Imperial College London

3 - Seeing Colour & Colour Spaces

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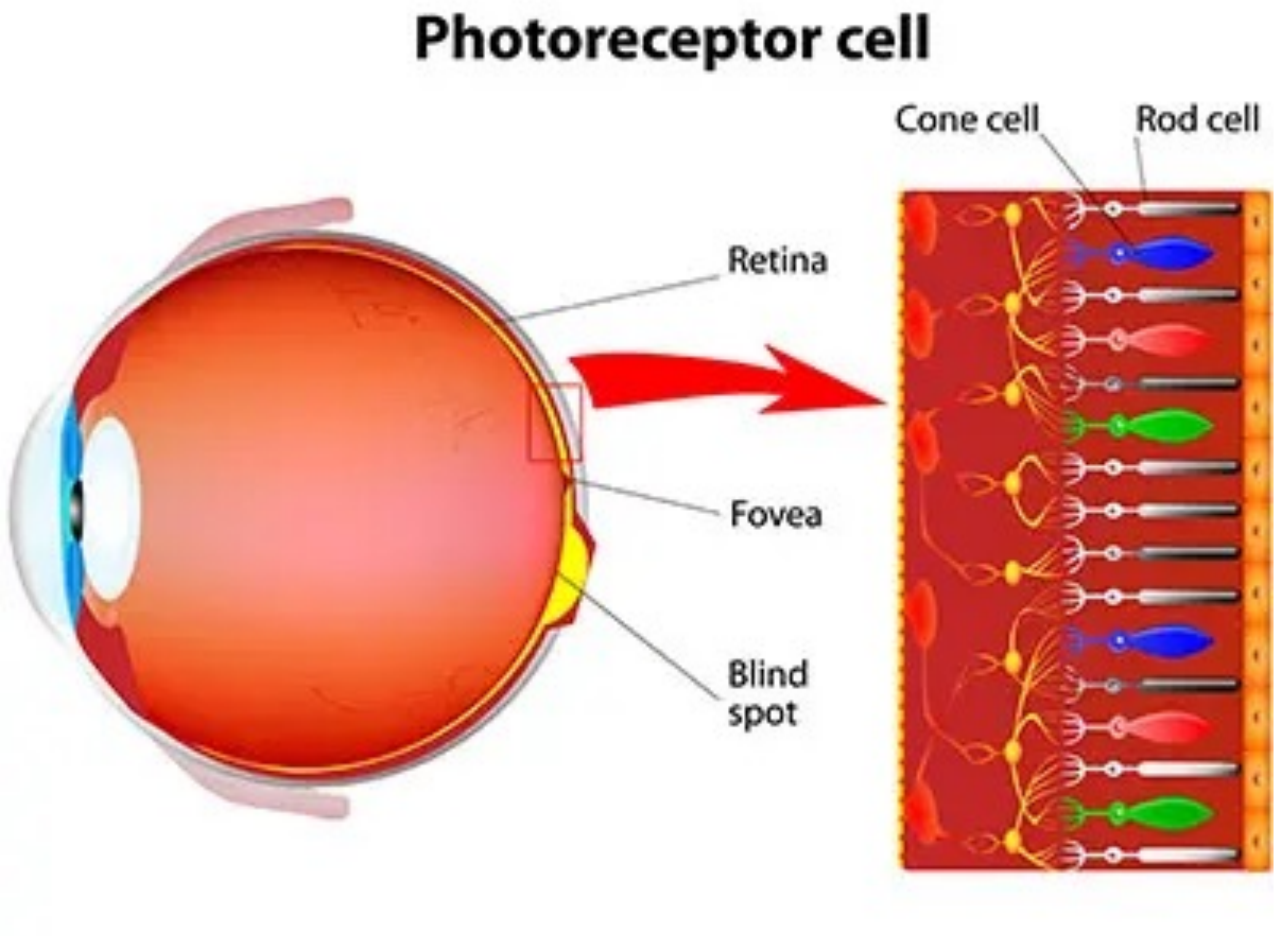
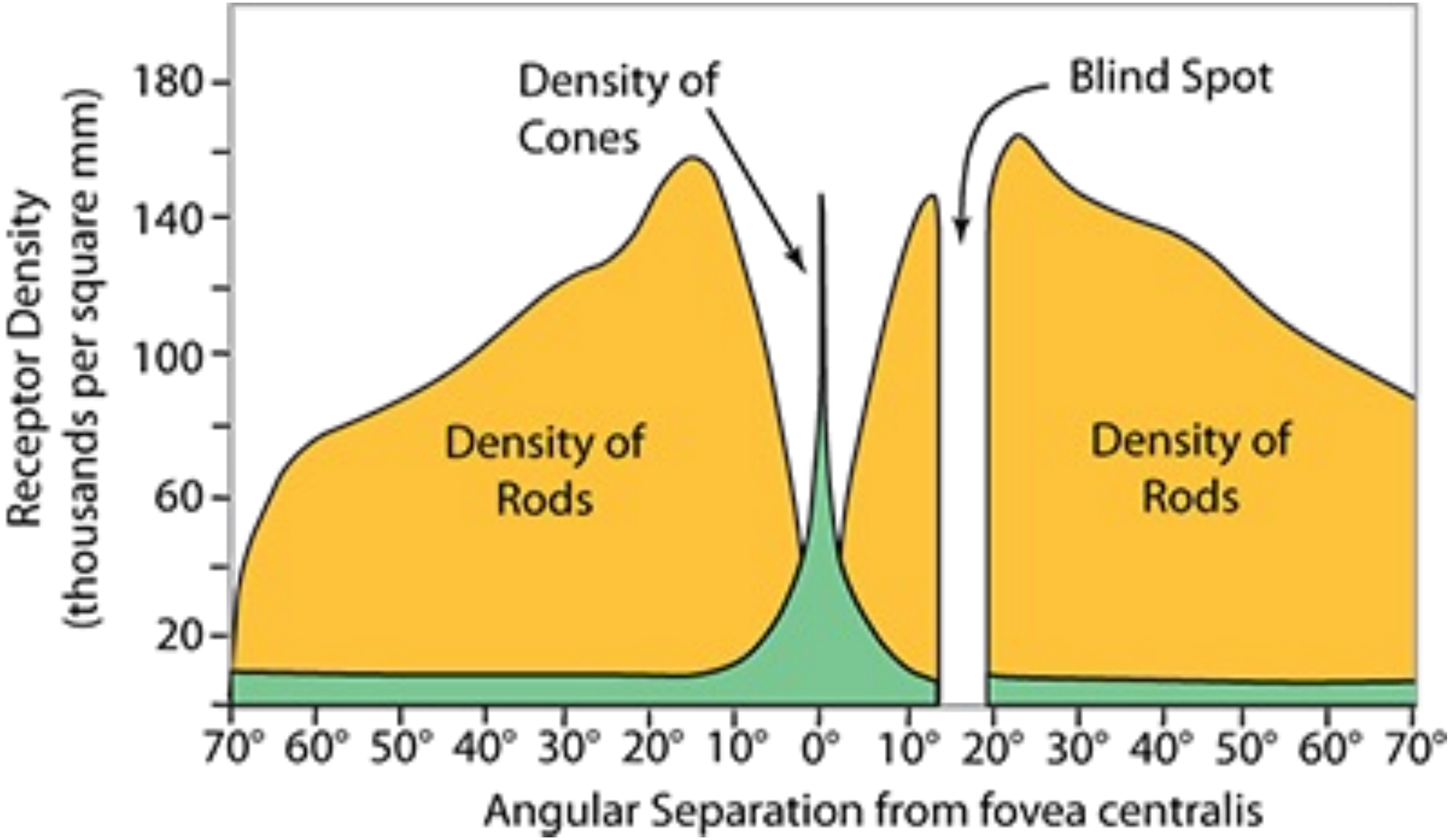
Photoreceptor cells in Retina



- Retina have three types of cones that are primarily responsible for seeing red, green and blue colours

Source: American Academy of Ophthalmology

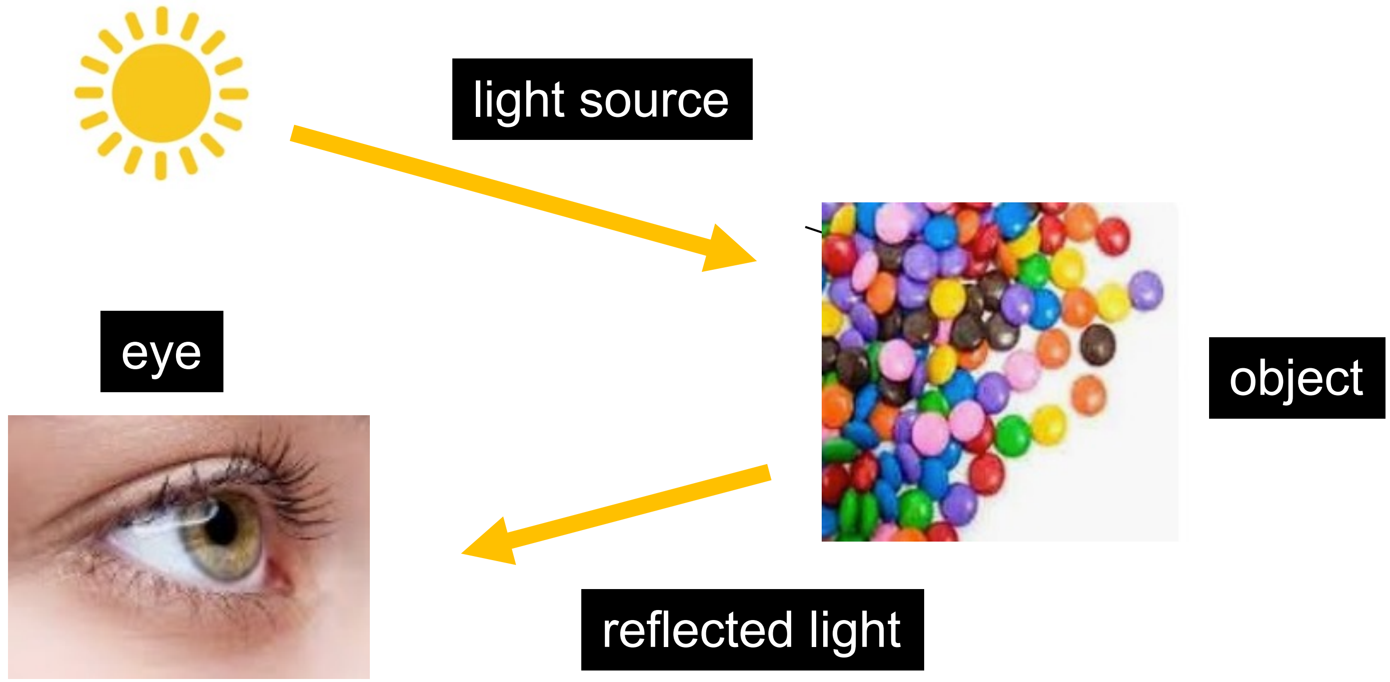
Densities of rods and cones



- Concentration of cones at very high density only in the fovea region, around ±6º around the centre of vision.
- Concentration of rod is spread out.

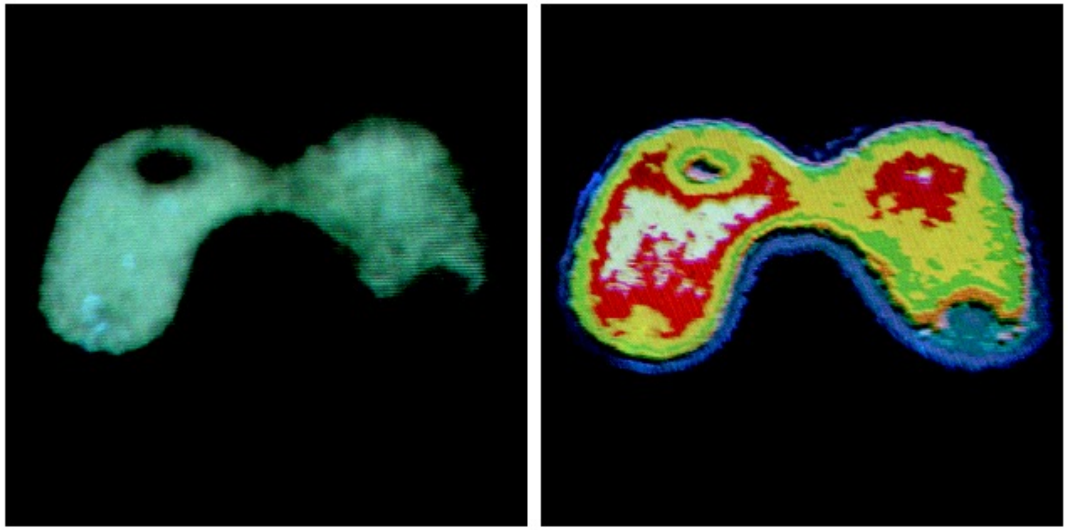
How we see colour of objects?

- The colour that human perceive in an object = the light reflected from the object



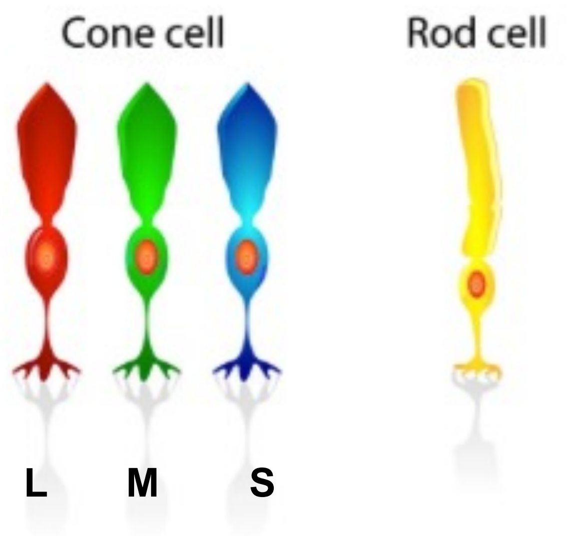
Why use Colour in Visual Systems

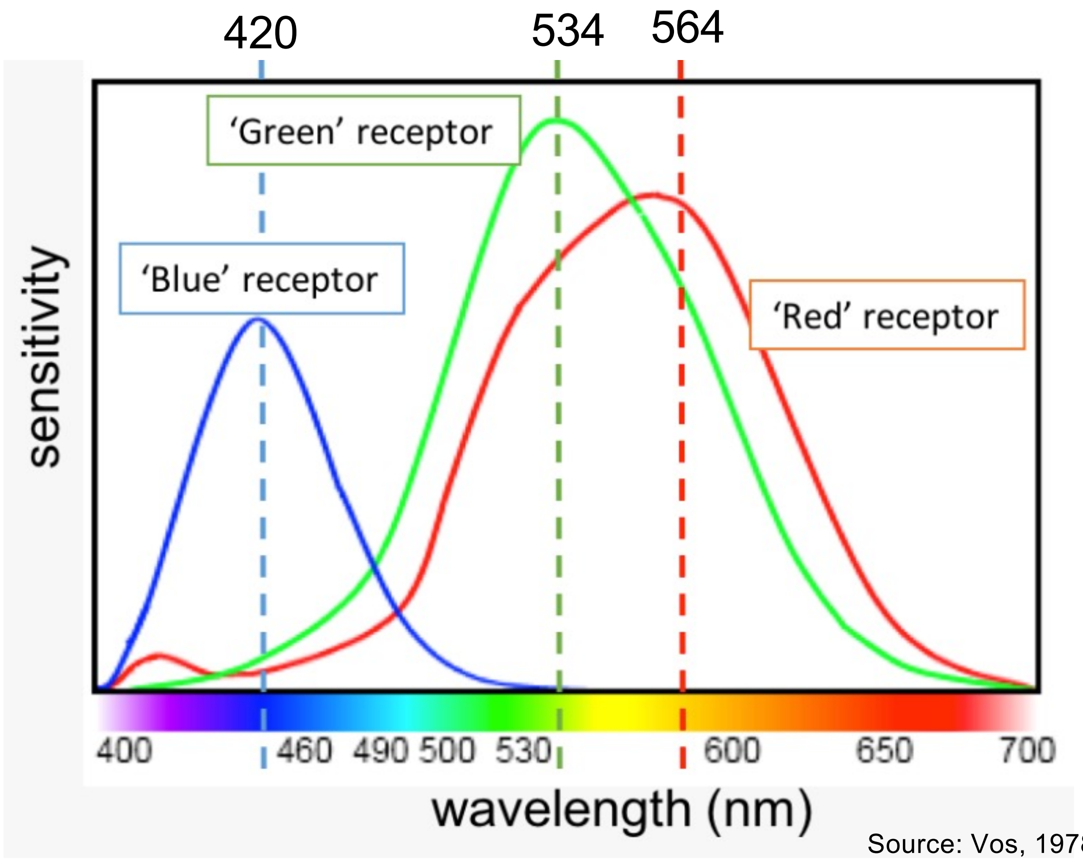
- Why use color in the design of visual systems?
  - Color is a powerful descriptor
    - ➢Object identification and extraction
    - ➢eg. Face detection using skin colors
  - Humans can discern thousands of color shades and intensities
    - ➢c.f. Human discern only two dozen shades of grays
- We even use false colour to characterize greyscale images (e.g. in medicine)



Trichromatic Theory

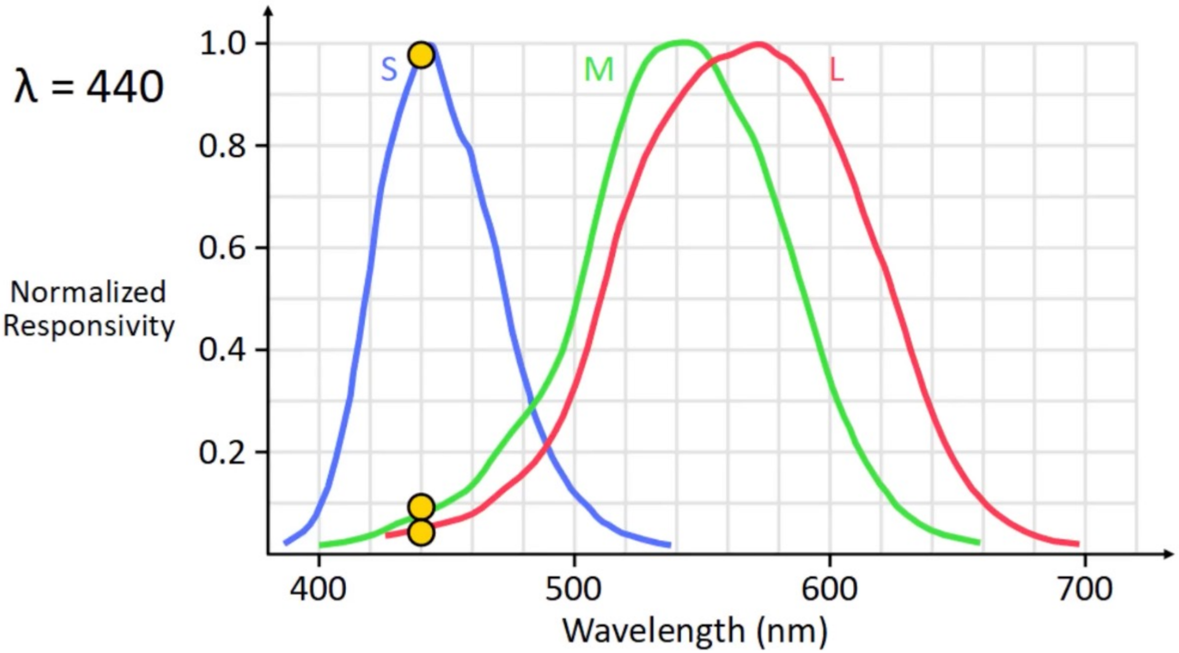
- Trichromatic theory (Young and Helmholtz)
  - Three types of cones in retina
  - Each type has photopigments sensitive to three different wavelengths
  - Red (long), Green (medium), Blue (short)

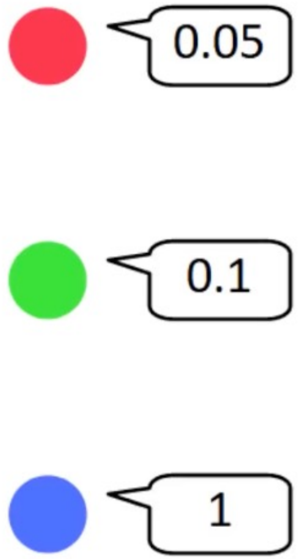




Source: Vos, 1978

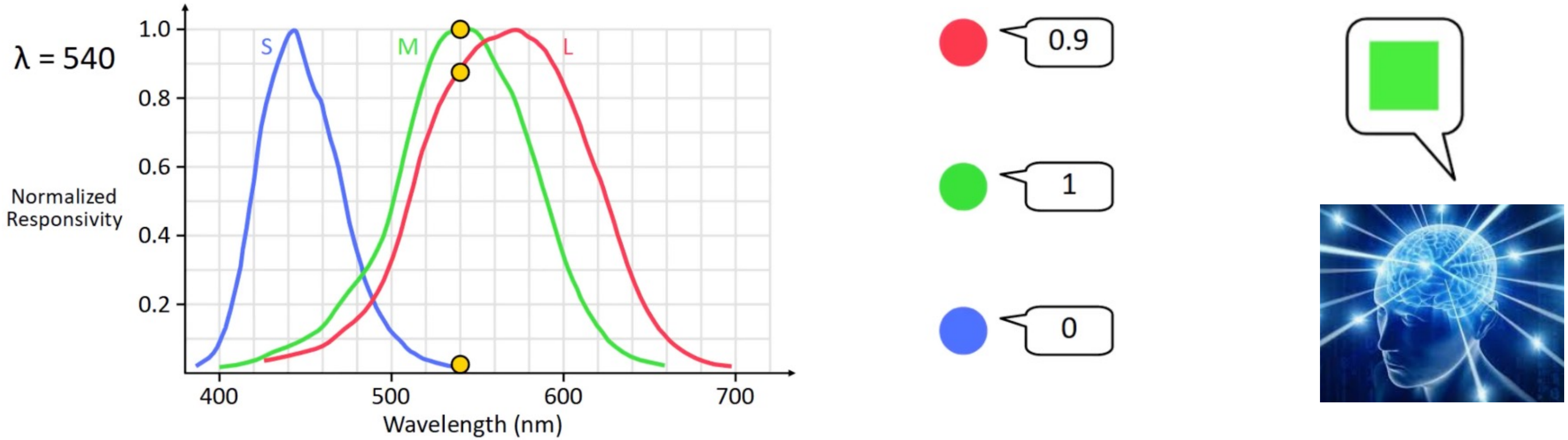
How does our brains ”see” blue?

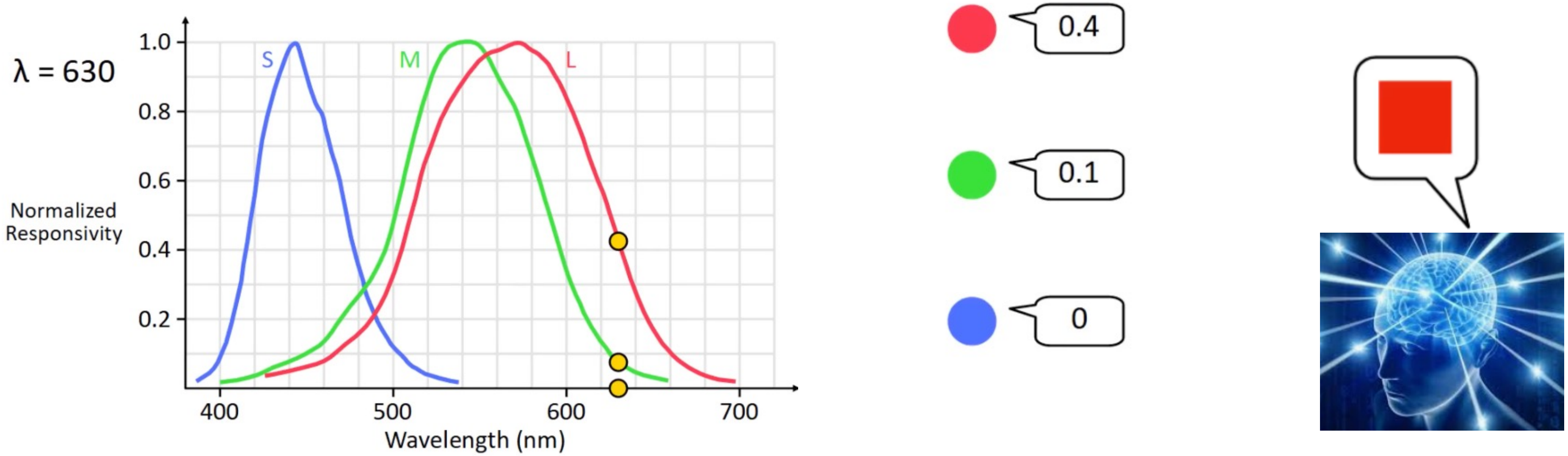




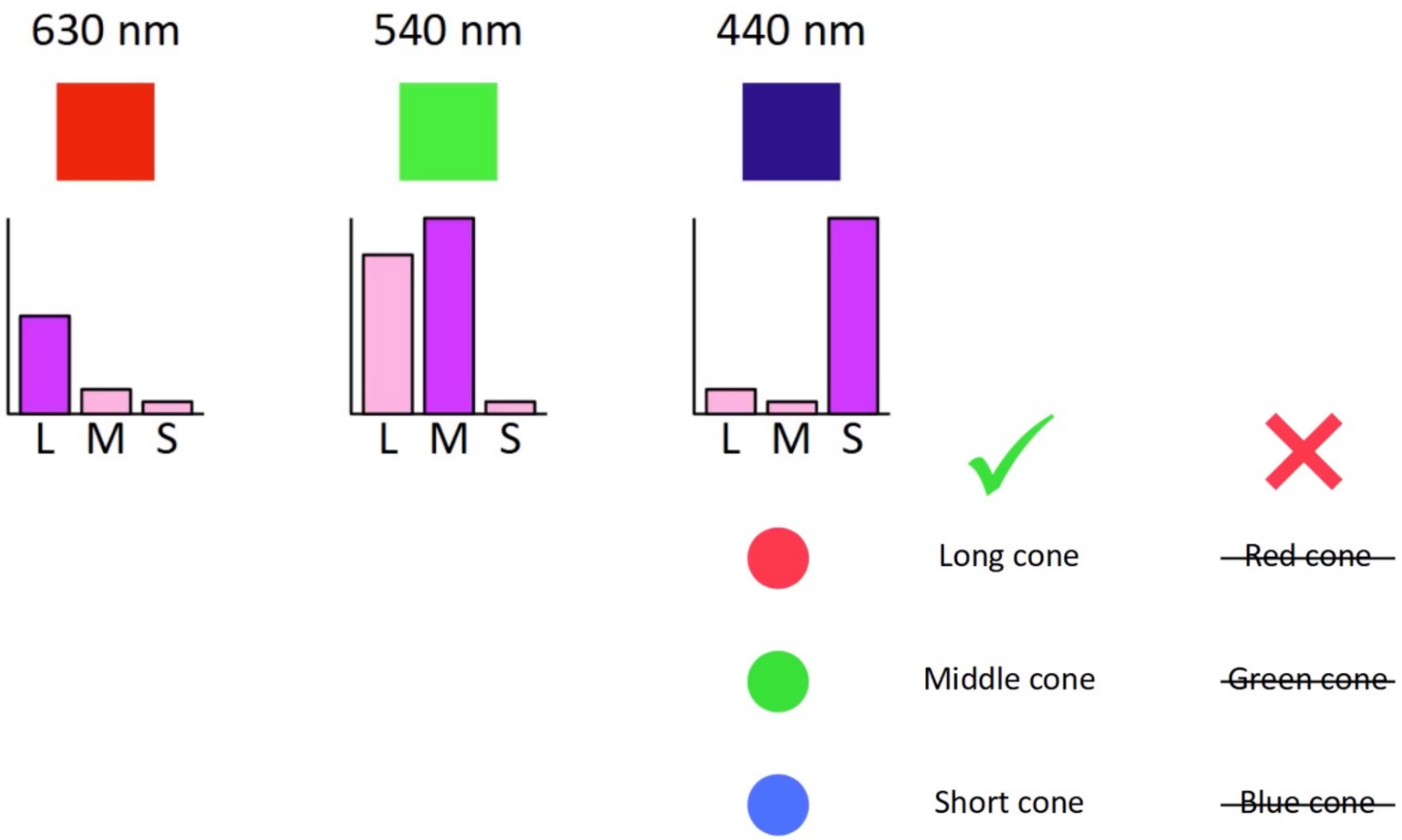
- Blue light at 440nm wavelength will strongly stimulate the S cone, but not the M and L cones.
- Our brain interprets this as blue colour.

"Seeing" green and red colours

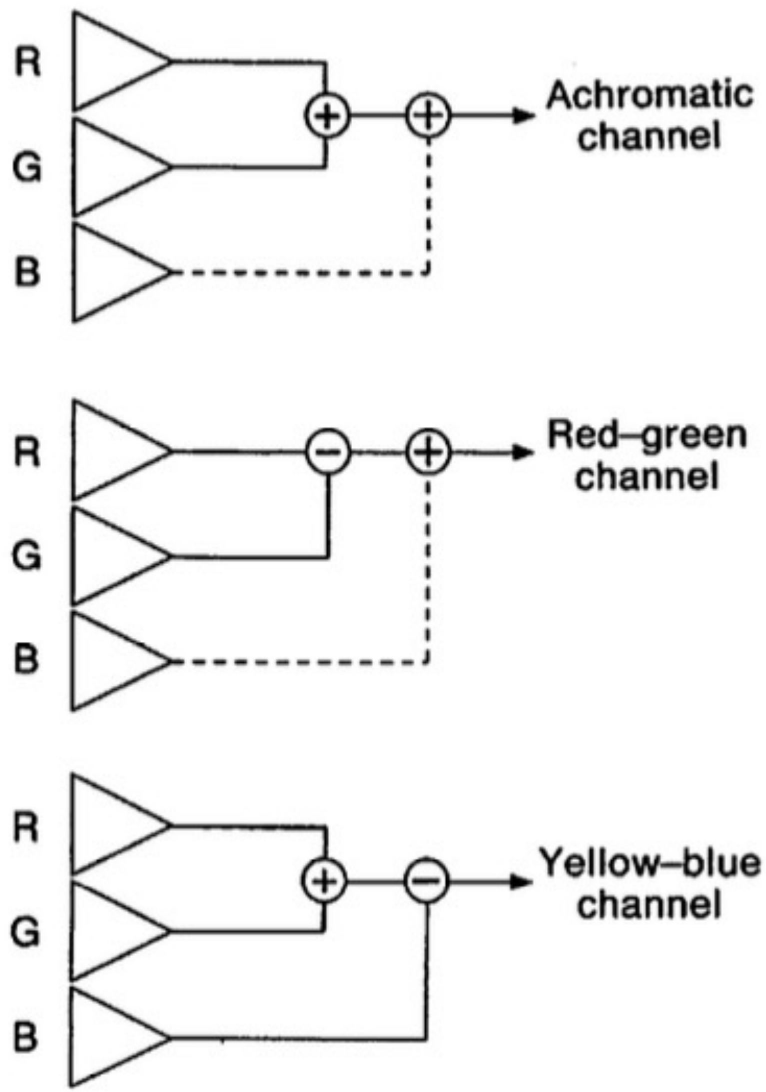




Don’t call them RGB, but LMS!



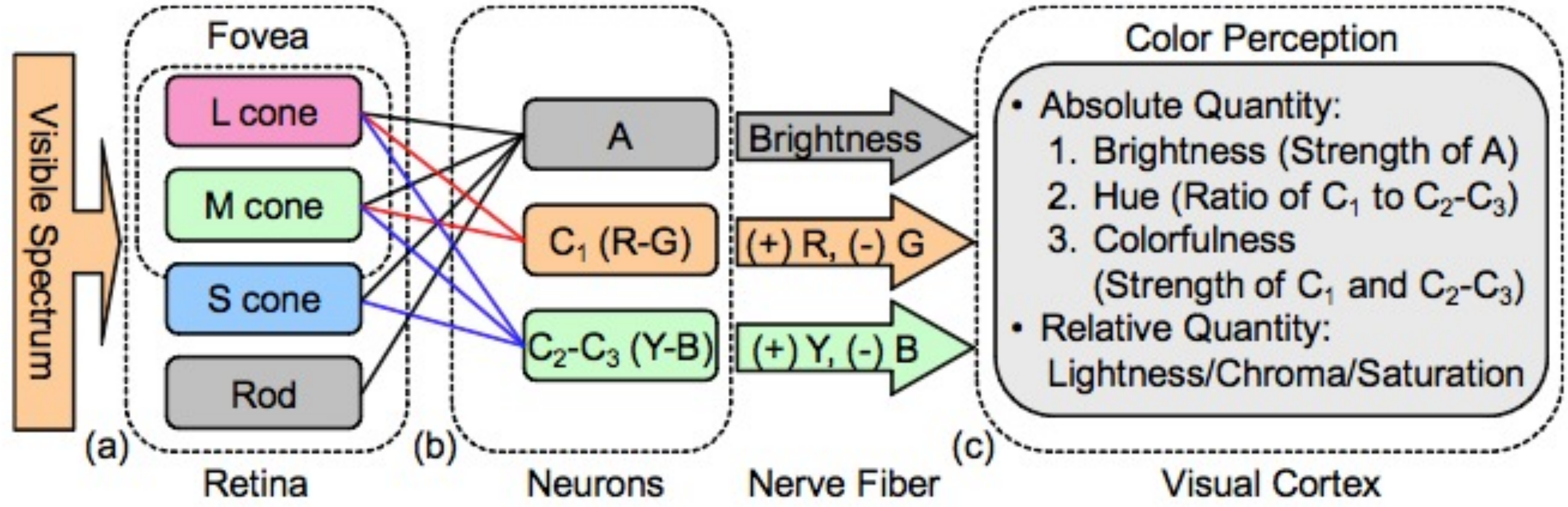
Opponent Process Theory (Herring)



- Three types of mechanisms combine cones signals in both additive and inhibitive ways.
- The achromatic channel is sensitive to all three cones and detects only the luminance information (i.e. black vs white)
- The Red-Green channel compares the difference in red and green cone signals (i.e. one inhibits the other)
- The Yellow-Blue channel compares the difference between blue cone signals with the sum of red and green signals.
- This theory explains some of the colour perception experiments in human visions

Source: Tovee p45-46

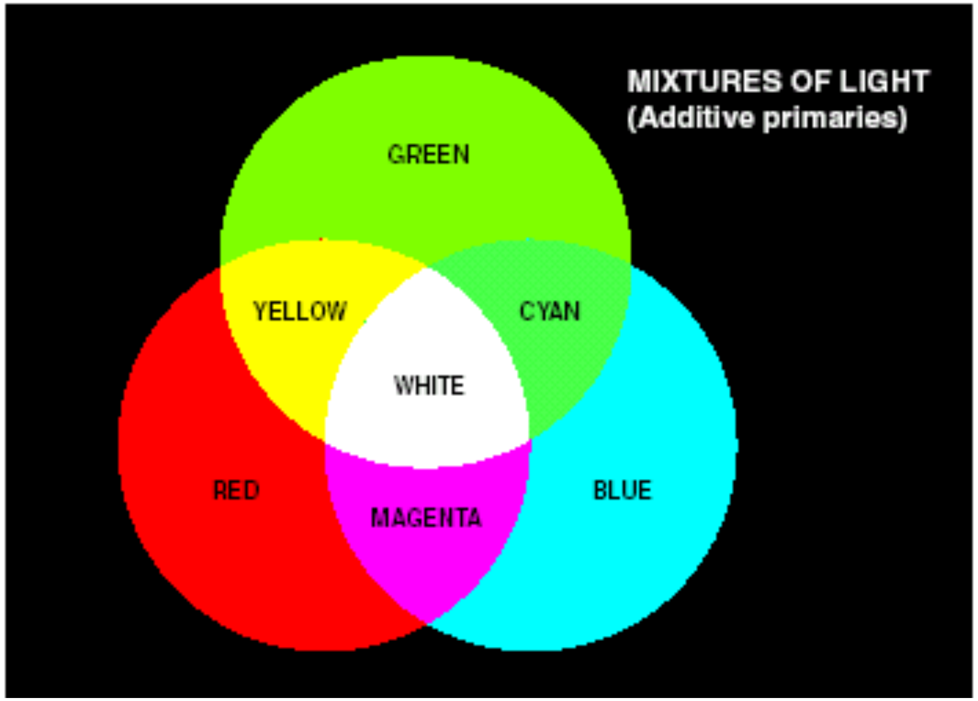
Opponent Process Theory of Colour Perception

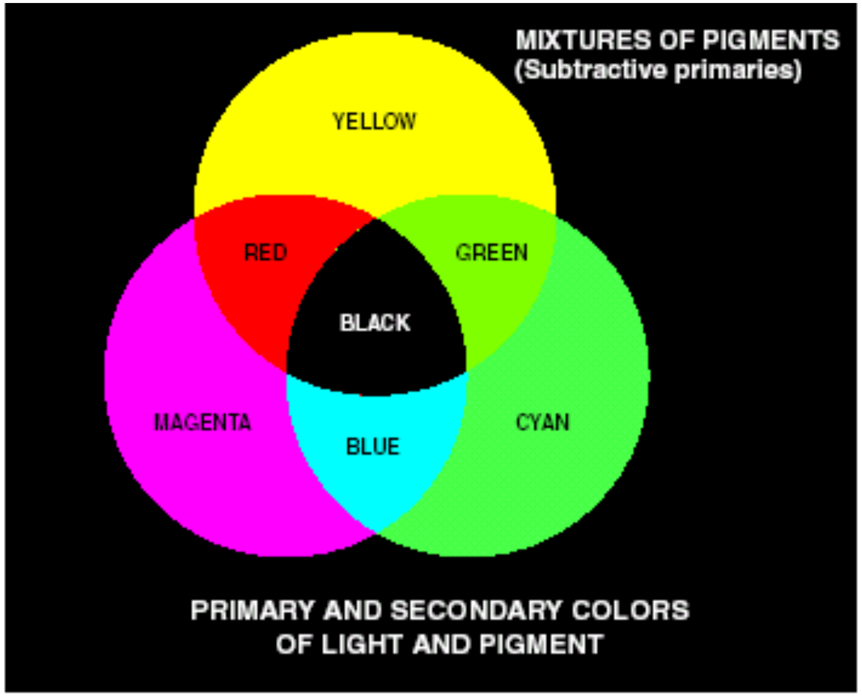


- Here is another view of how the opponent process theory explains our colour perception mechanism.

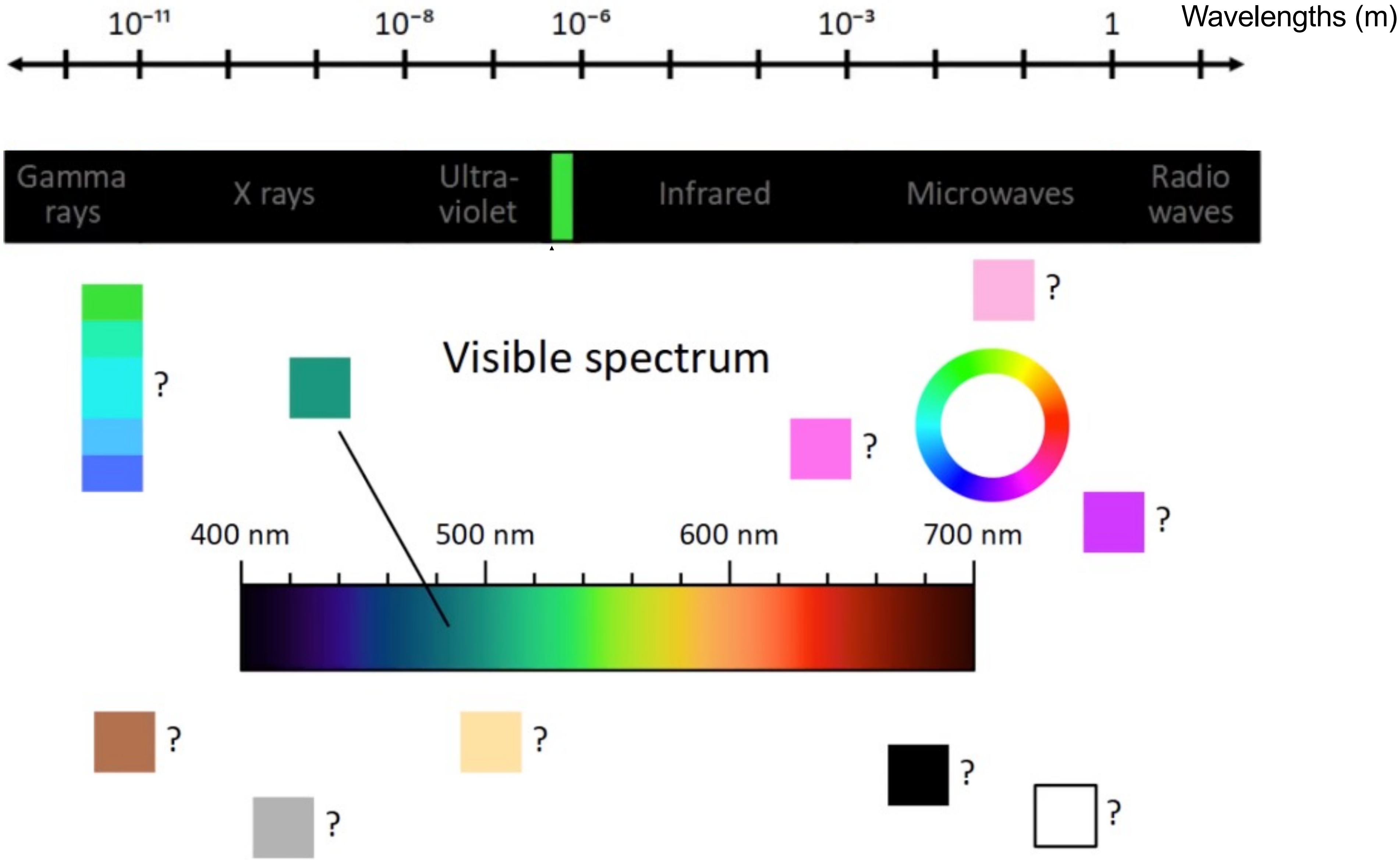
Primary and secondary colors

- In 1931, **CIE**(International Commission on Illumination) defines specific wavelength values to the **primary colours**
  - B = 435.8 nm, G = 546.1 nm, R = 700 nm
  - However, we know that <u>no single color</u> may be called red, green, or blue
- **Secondary colours**: G+B=**C**yan, R+G=**Y**ellow, R+B=**M**agenta

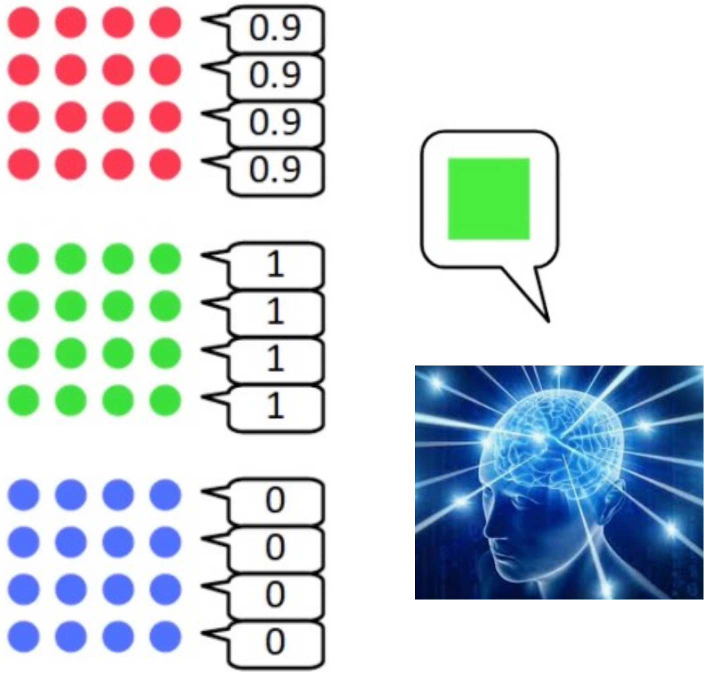


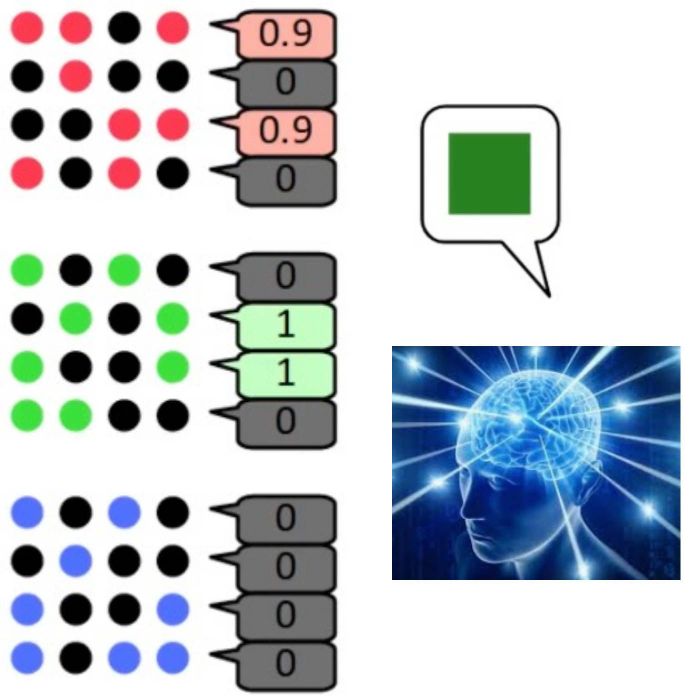


Limitation of the visible spectrum



The idea of luminance and chrominance



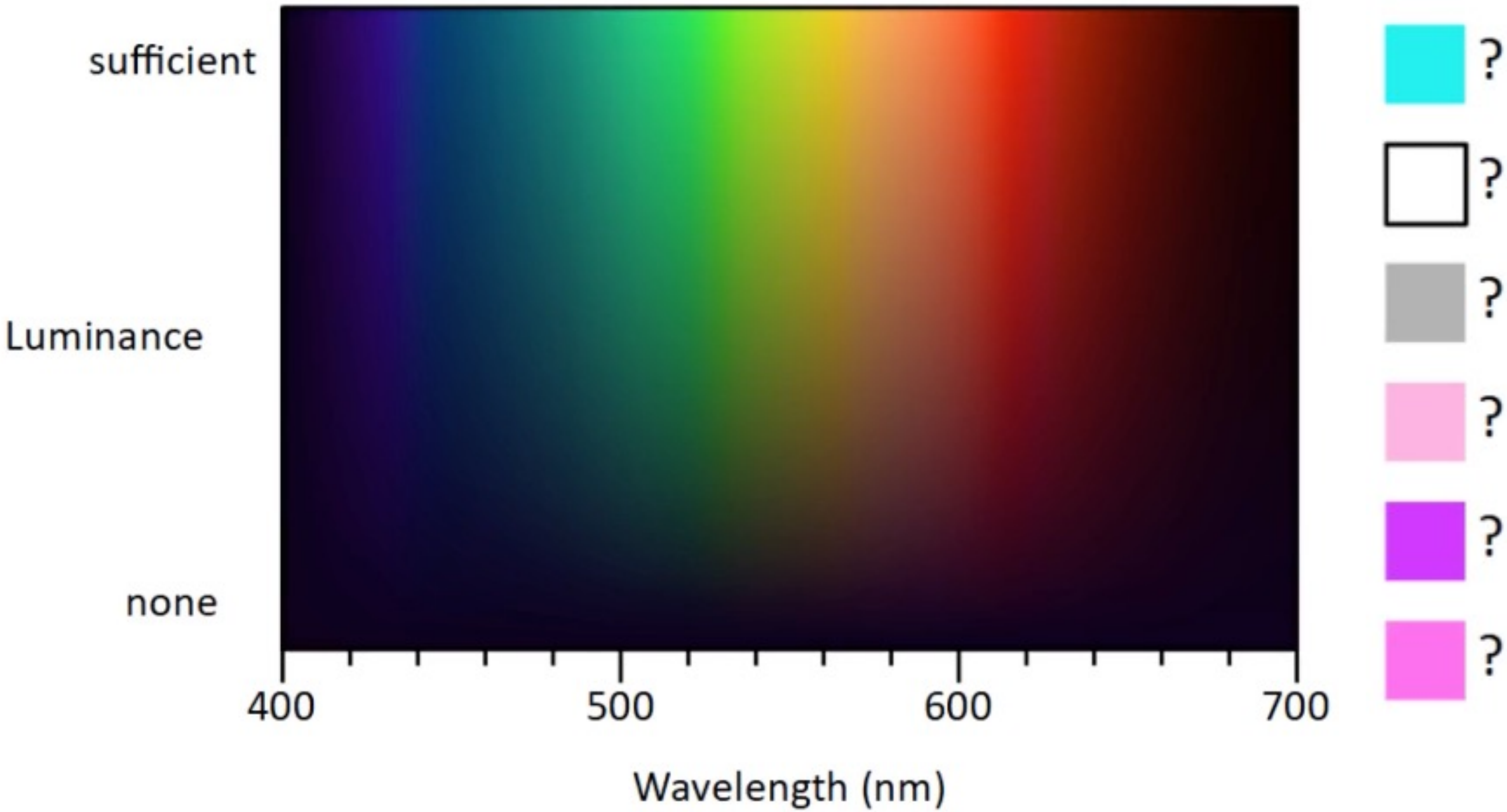


Dark (Black)

Luminance scale for the colour green

Bright green

Luminance vs Wavelength is not sufficient

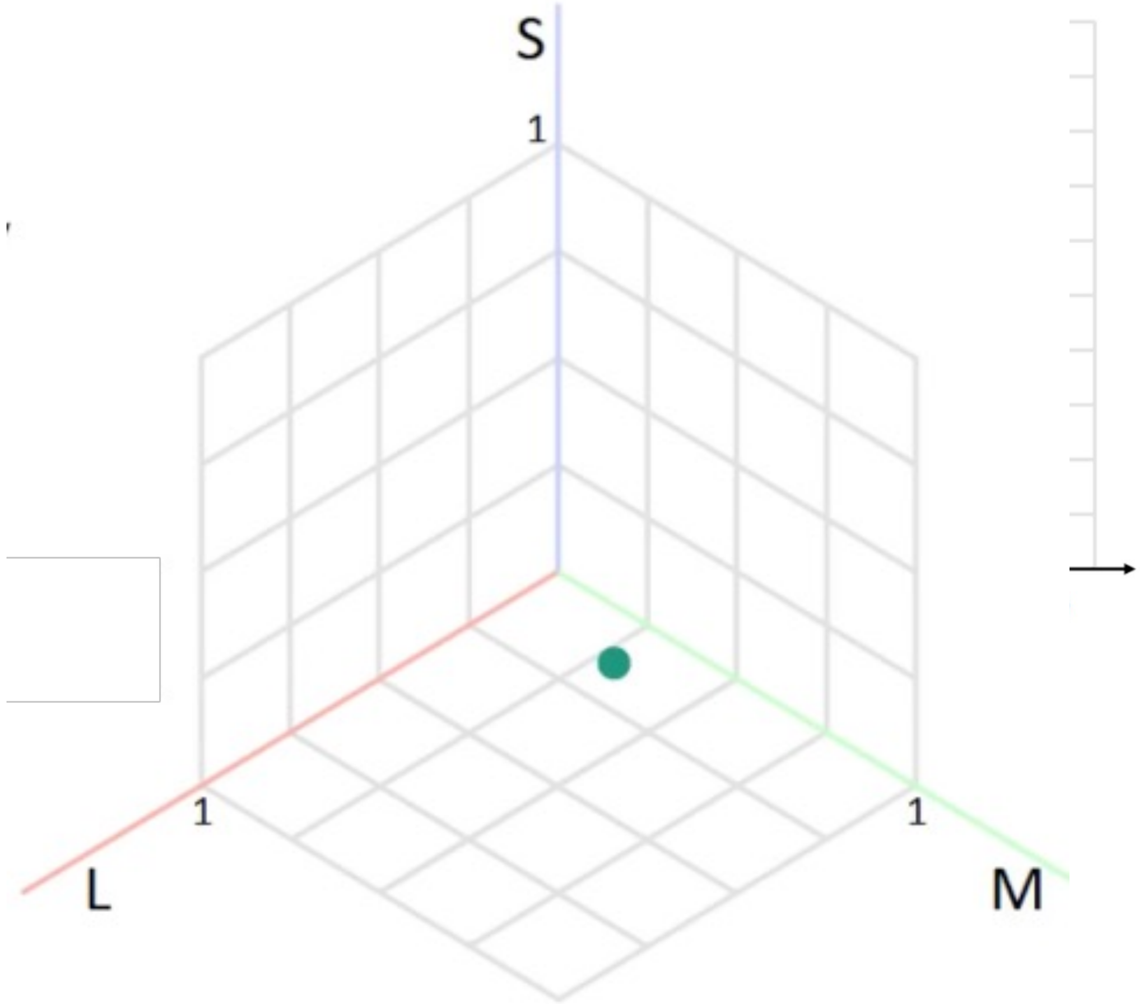


LMS Colour Space

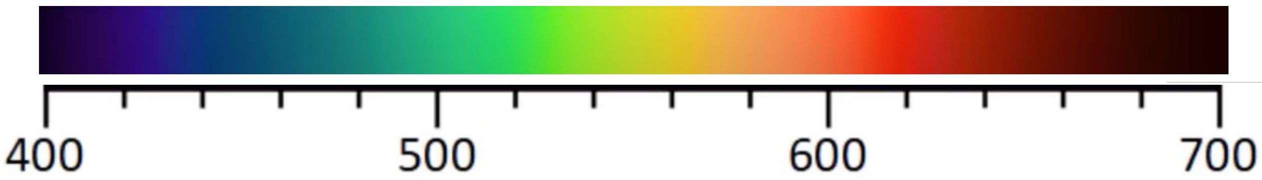
λ = 500 nm

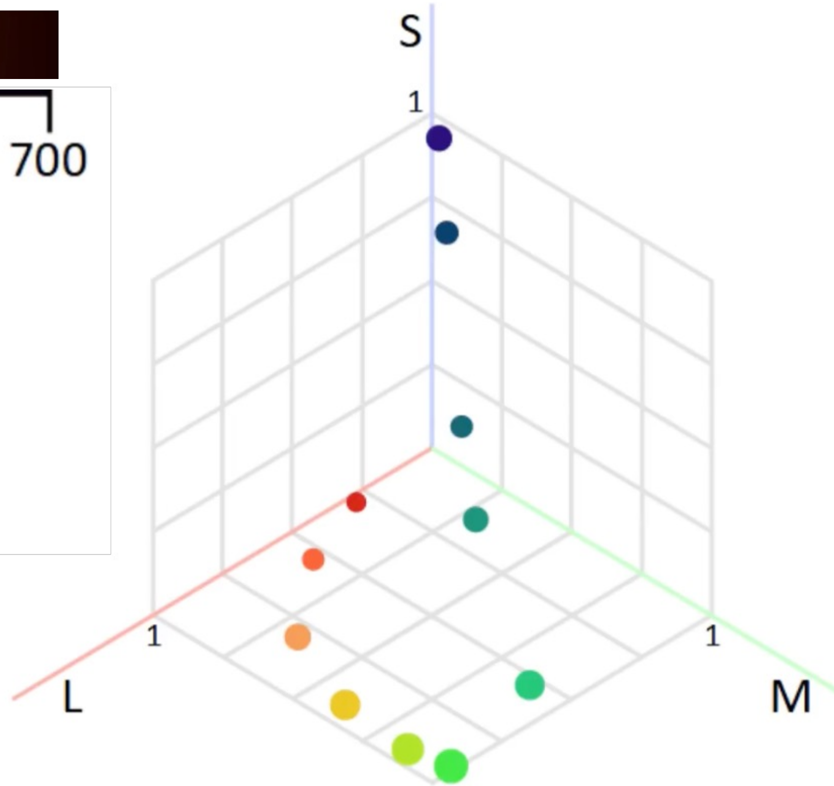
L = 0.3
M = 0.5
S = 0.1

$$\begin{bmatrix} 0.3 \\ 0.5 \\ 0.1 \end{bmatrix}$$

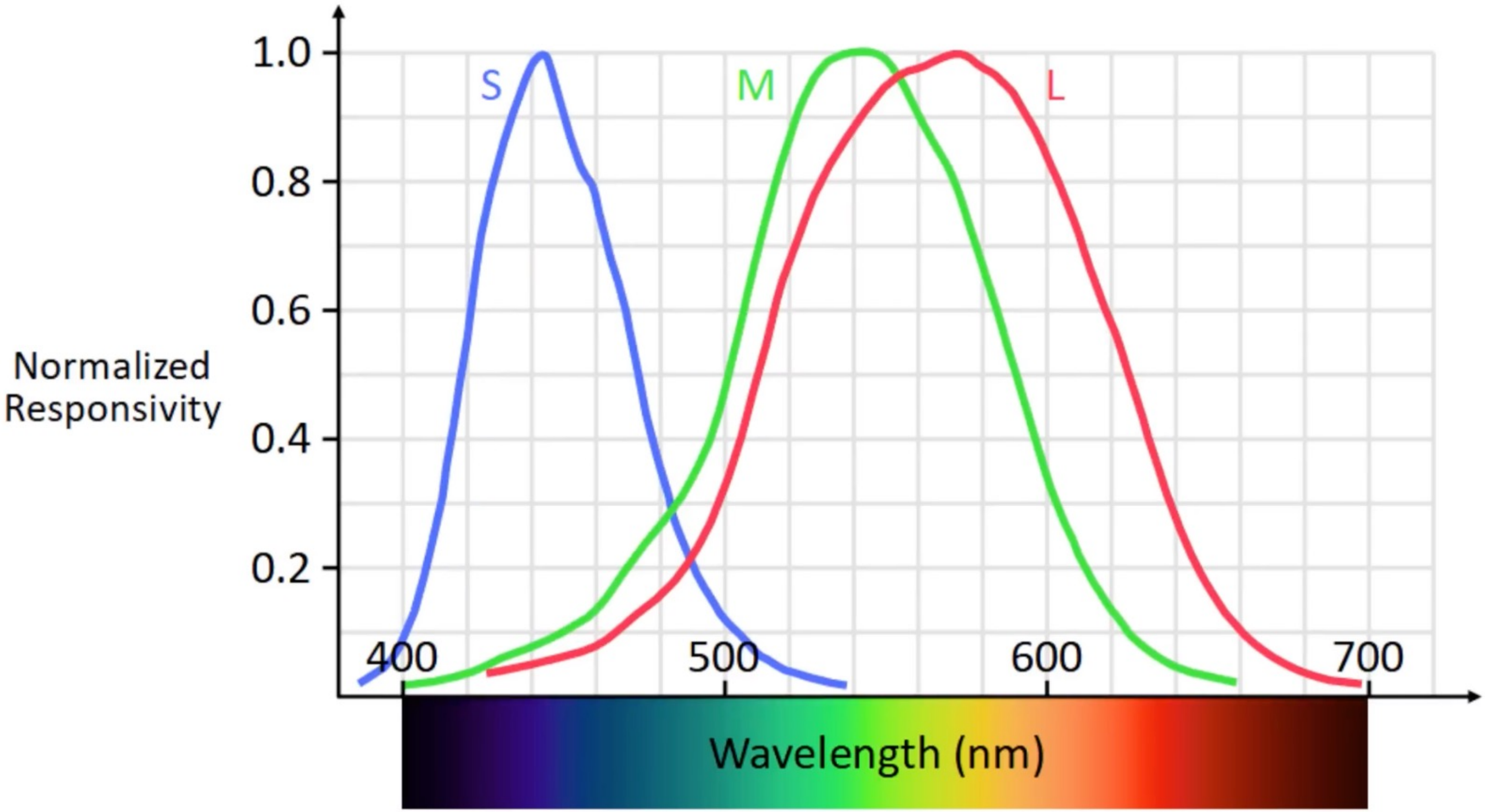


Mapping wavelengths of colour to 3D space





Normalised Cone Responses



Gaussian Approximation

$$y = e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}$$

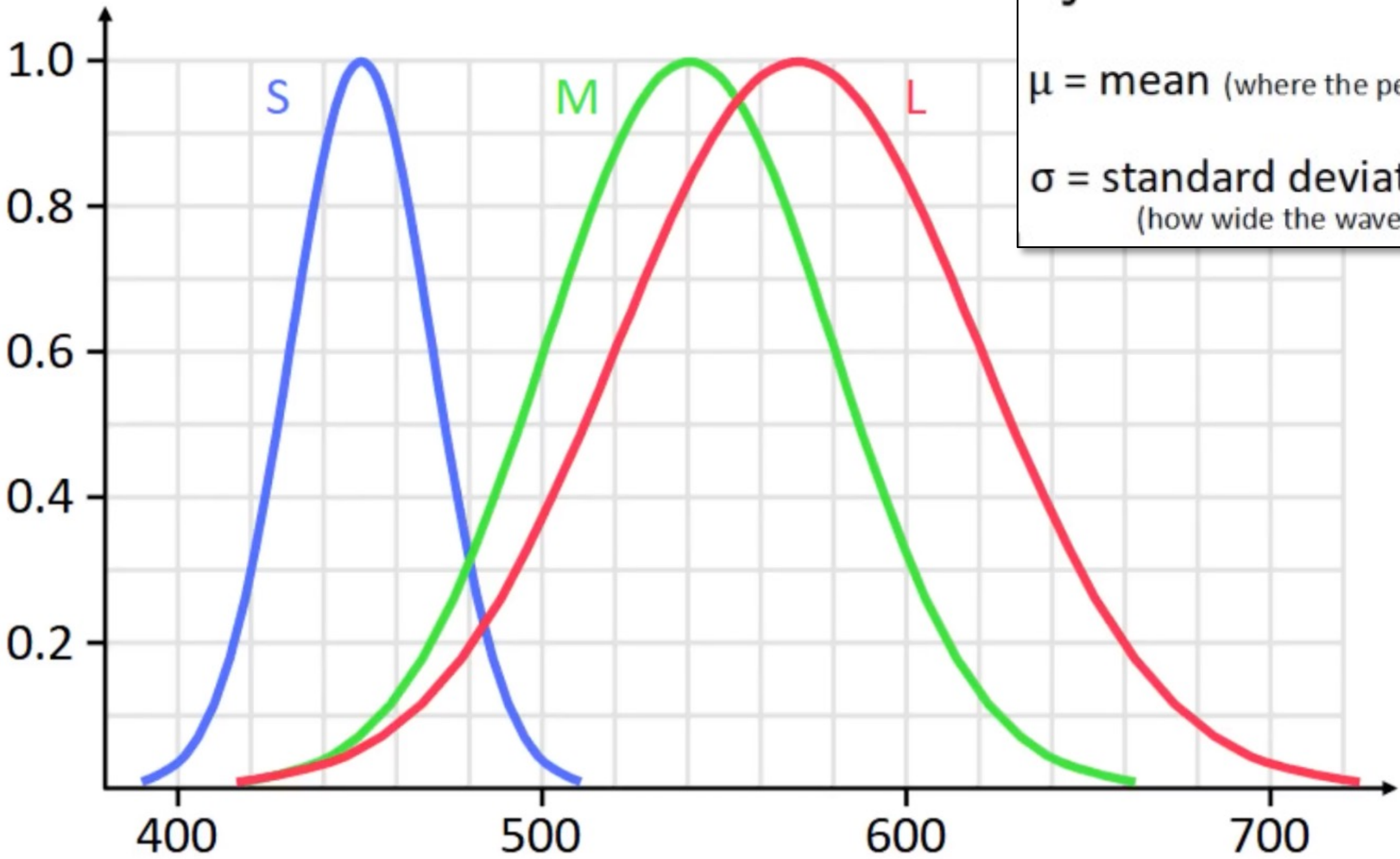
μ = mean (where the peak is)

σ = standard deviation (how wide the wave is)

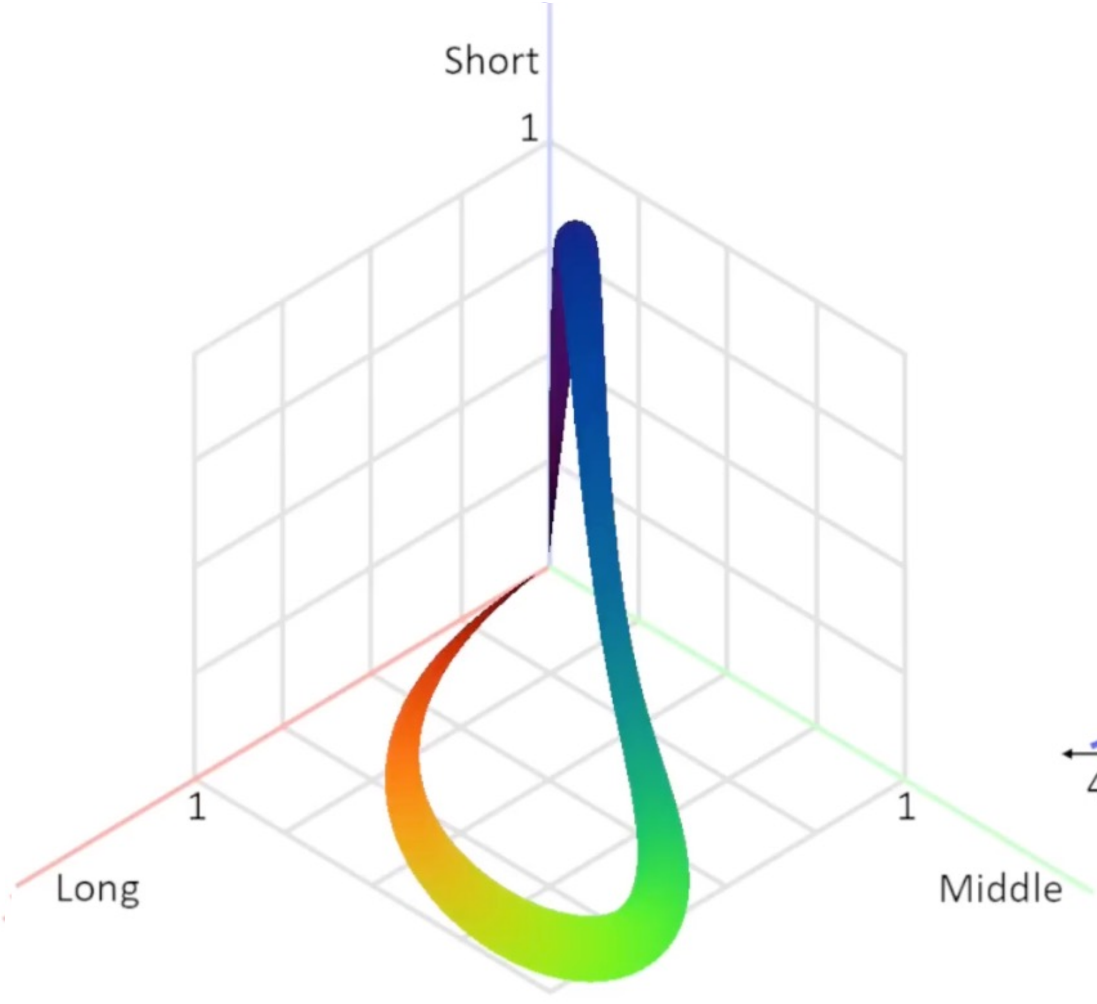
μ = 570
σ = 50

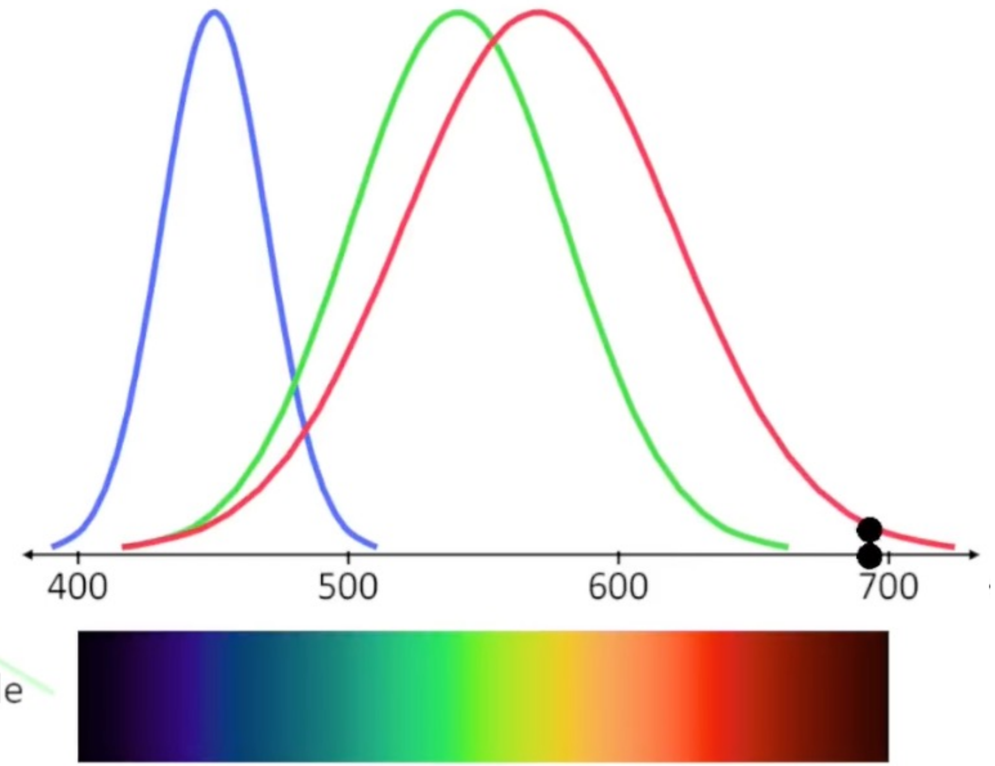
μ = 540
σ = 40

μ = 450
σ = 20

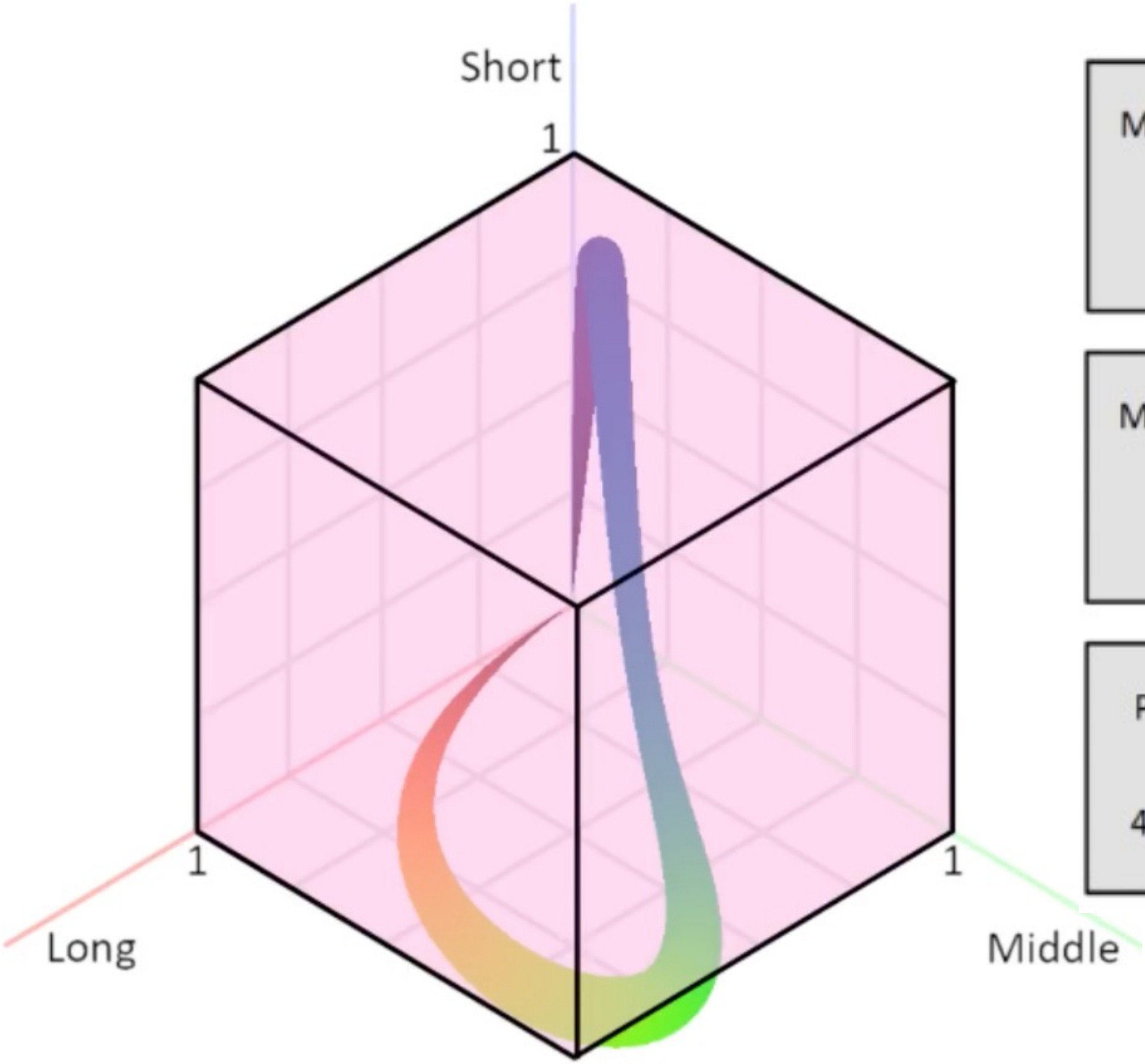


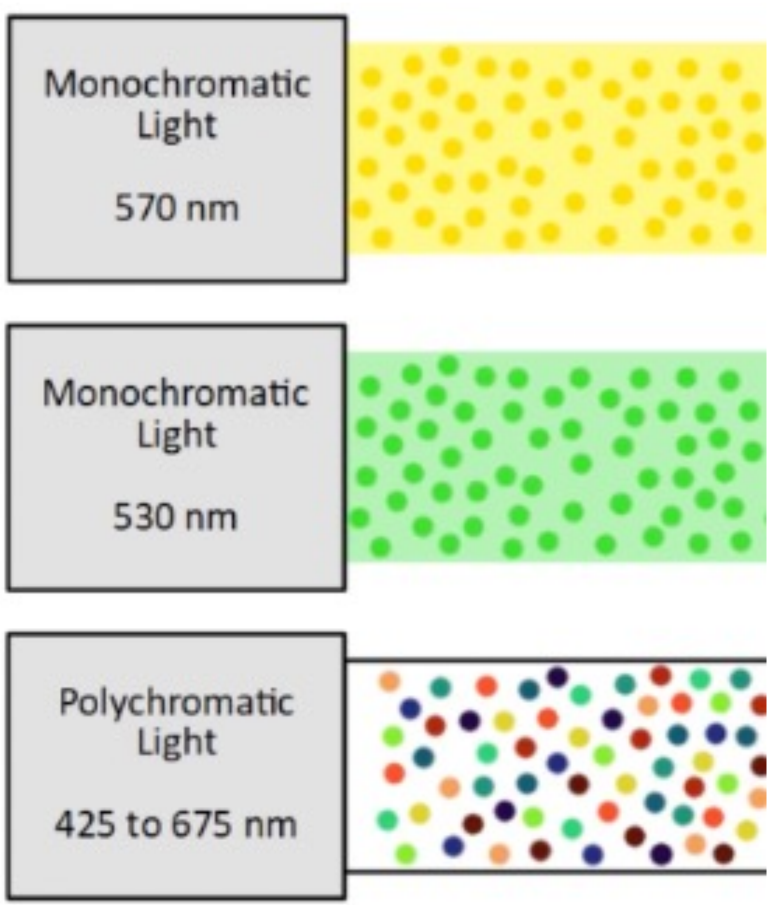
Visible Spectrum mapped onto LMS space



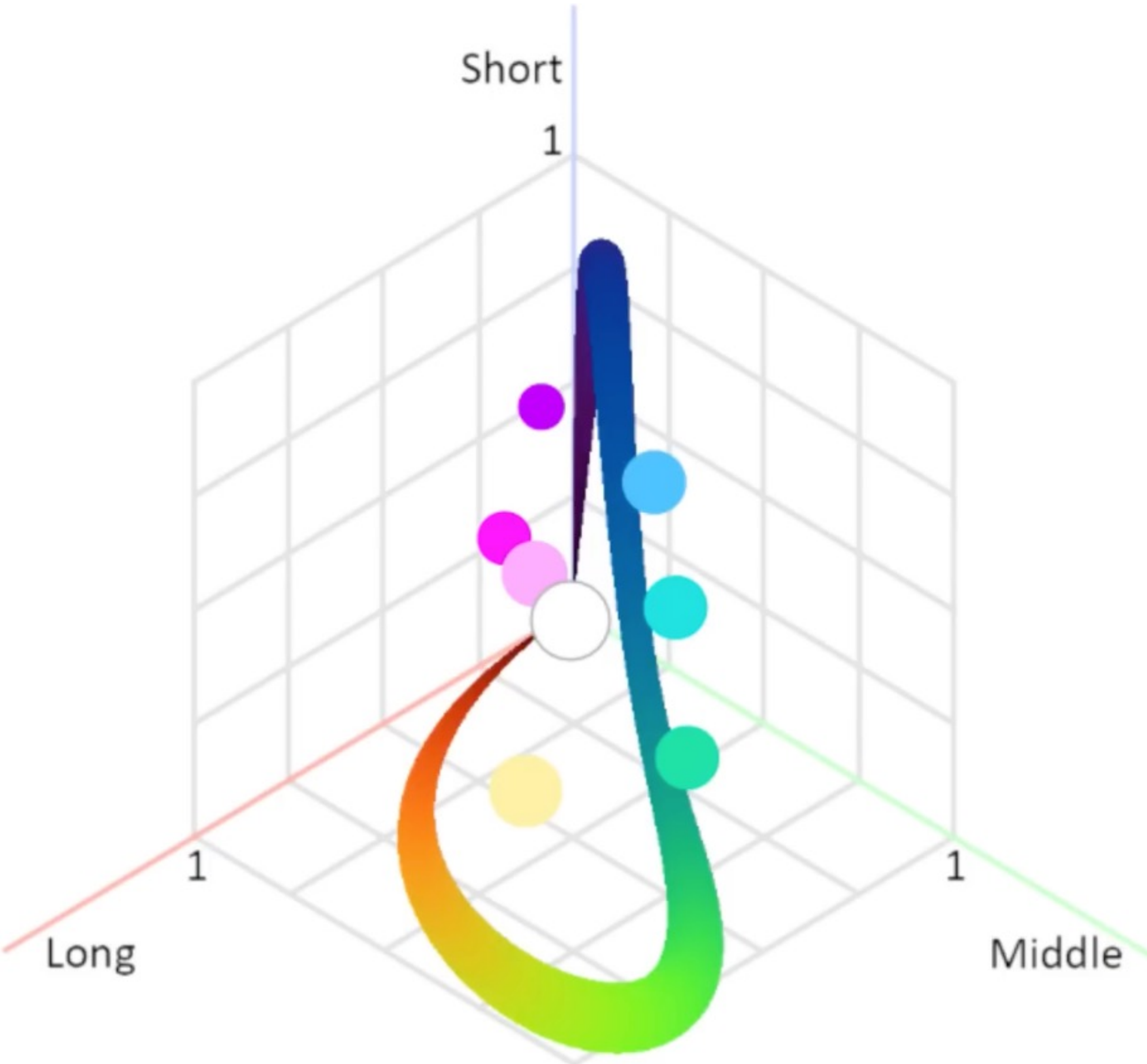


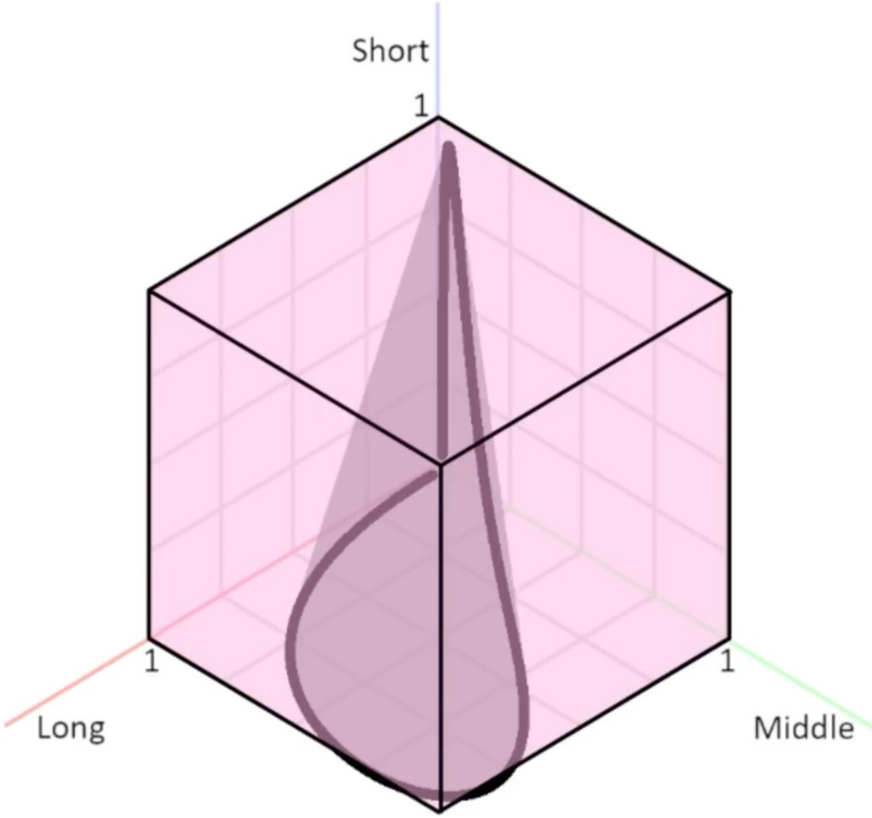
LMS cube can have many more colours



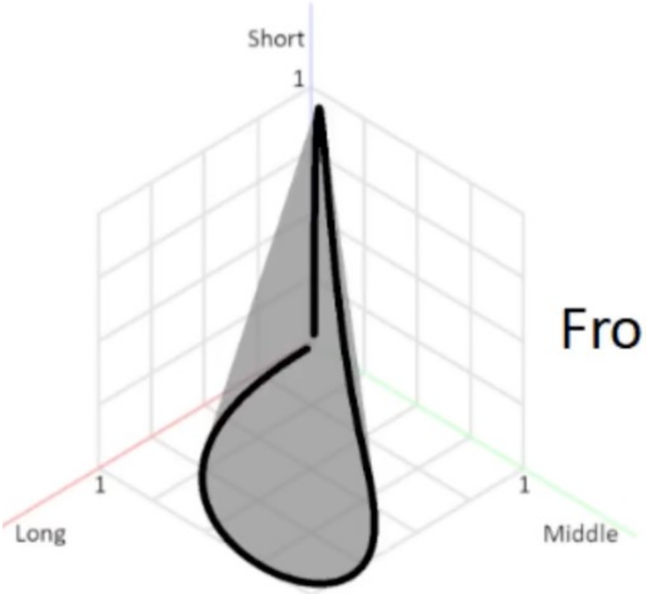


More colours in the 3D Colour Space



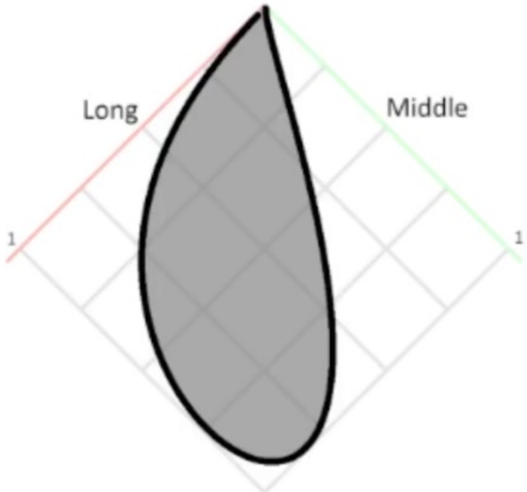


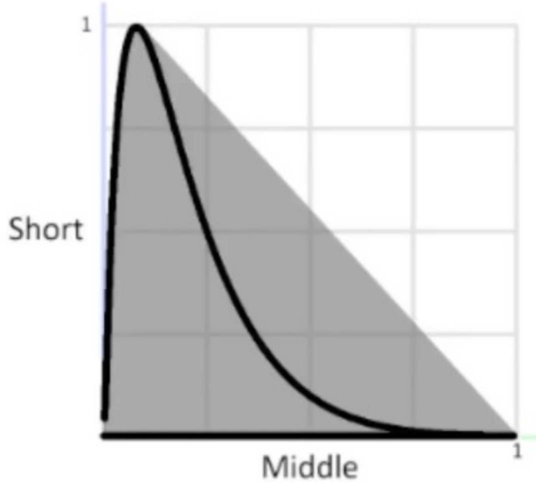
The Visible Gamut



Front view

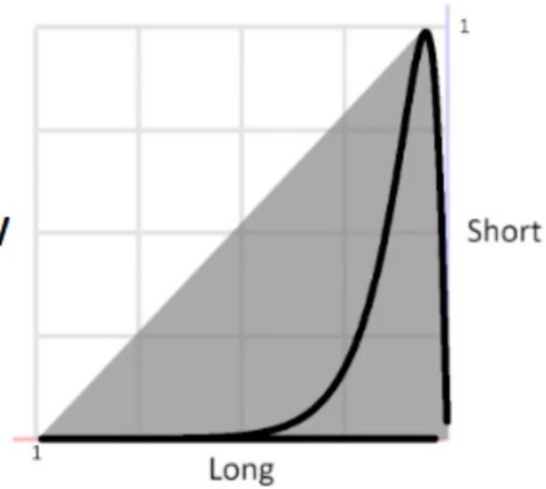
Top view



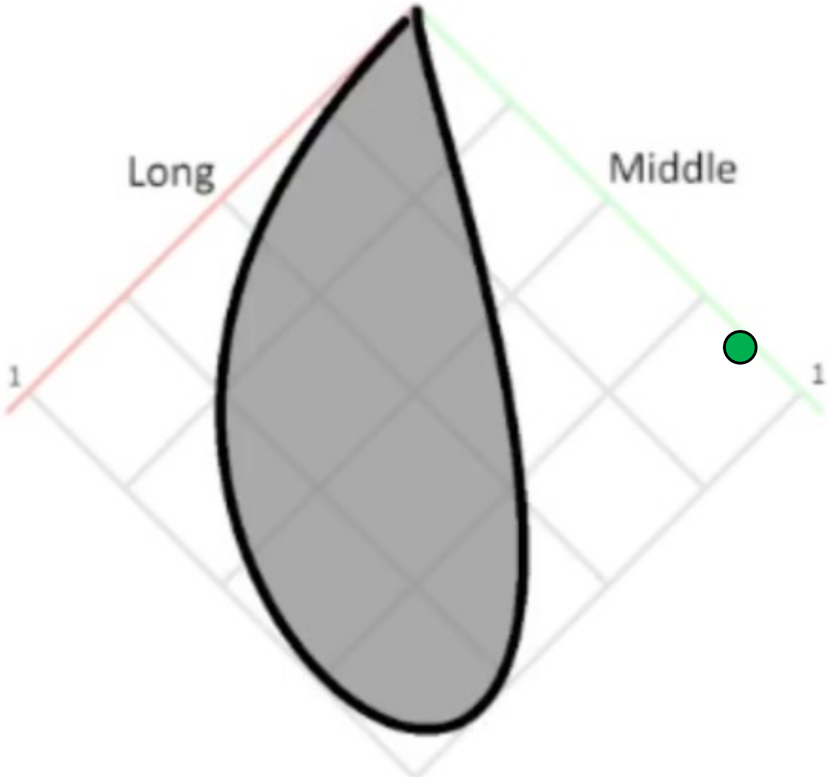


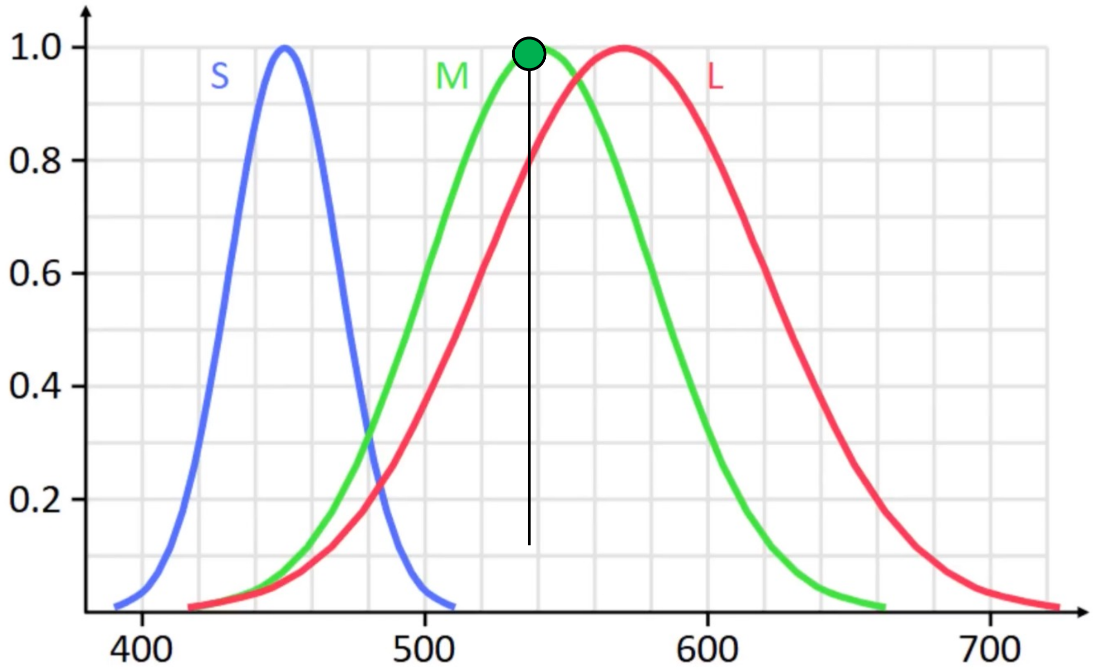
Left view

Right view

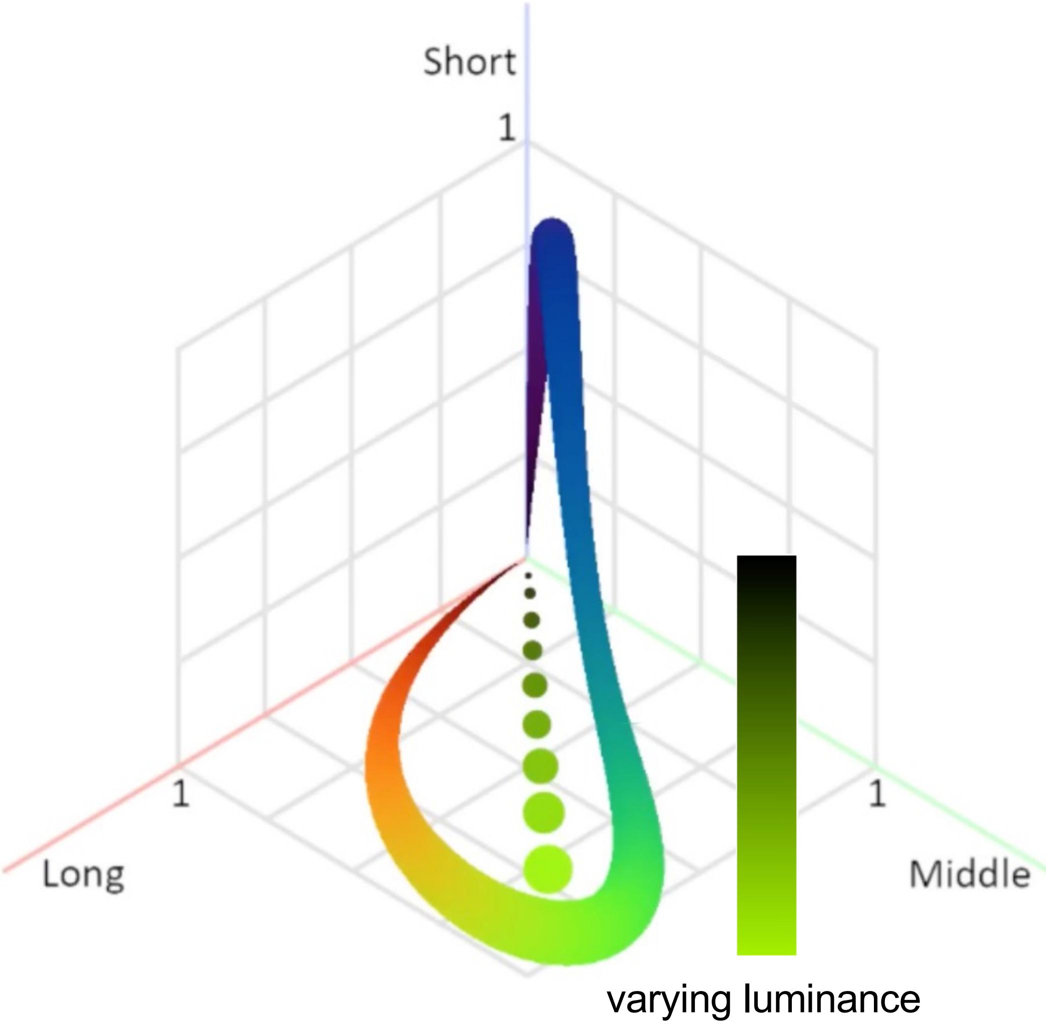


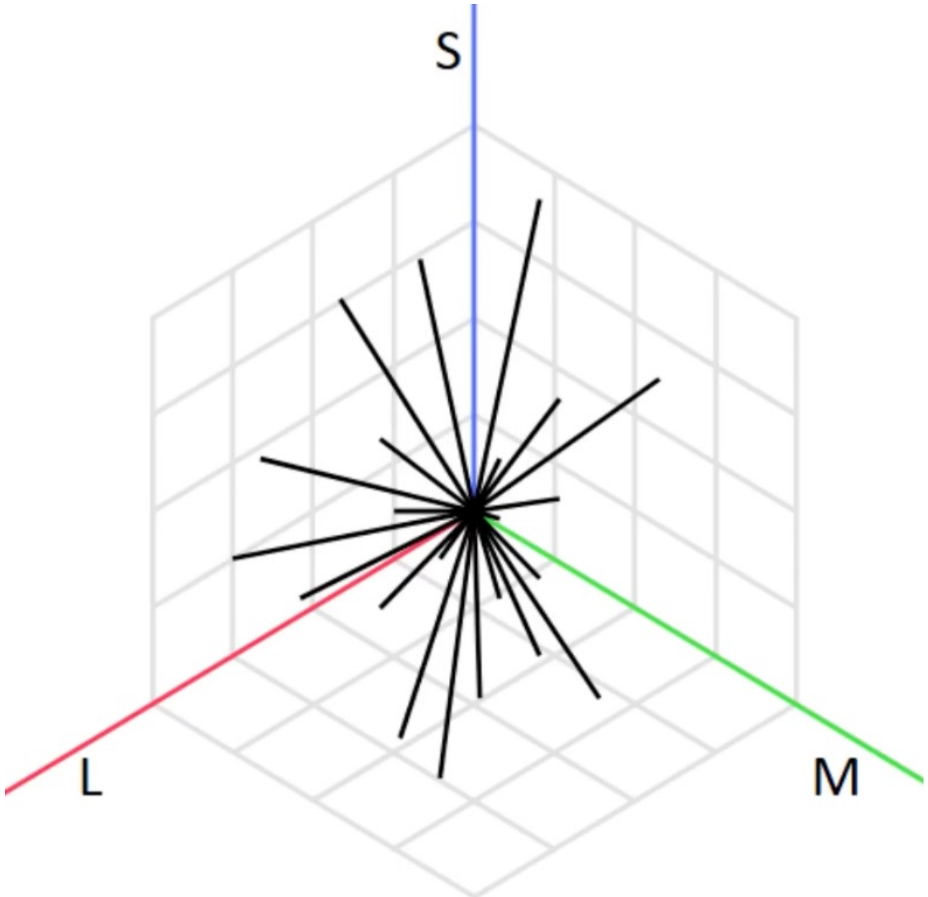
Why are some colour impossible in 3D Space?



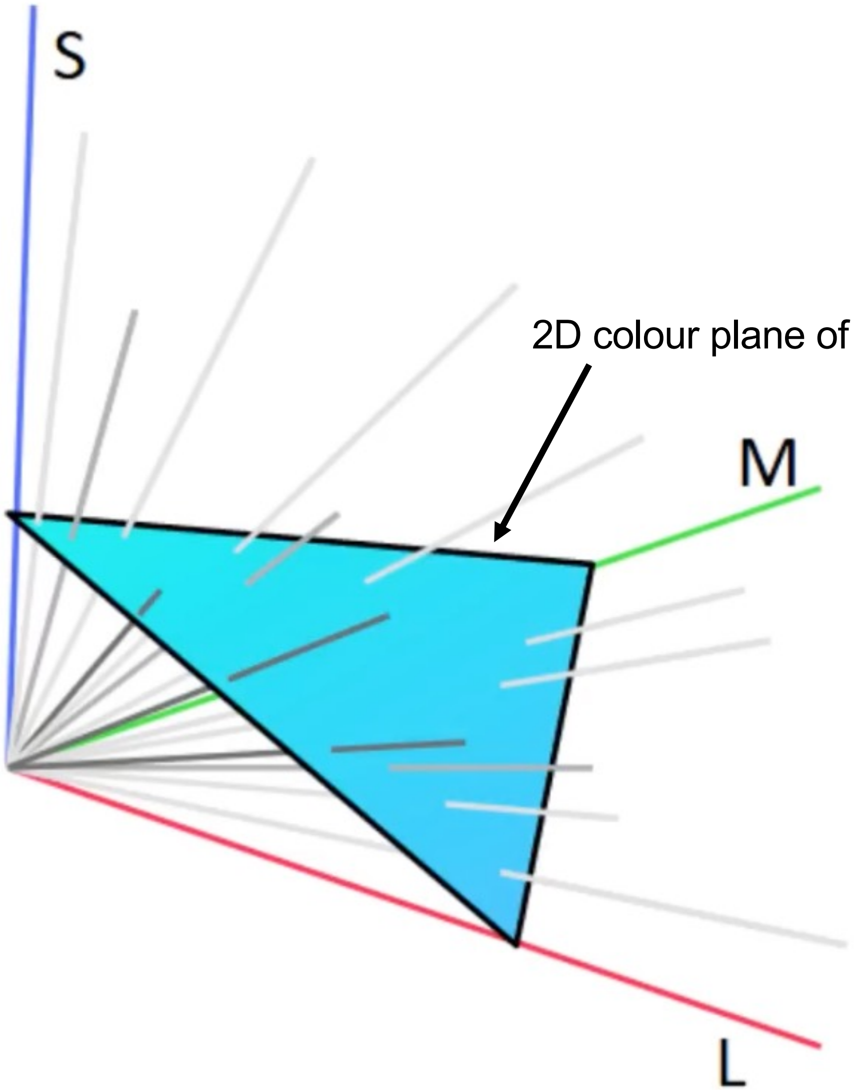


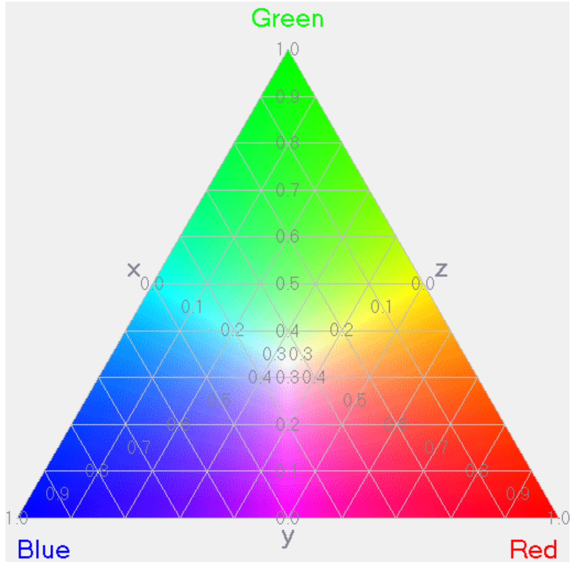
Constant Colour (Chromaticity)

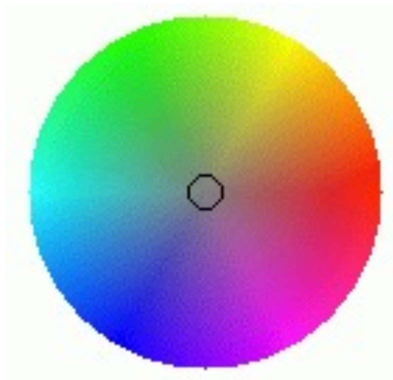




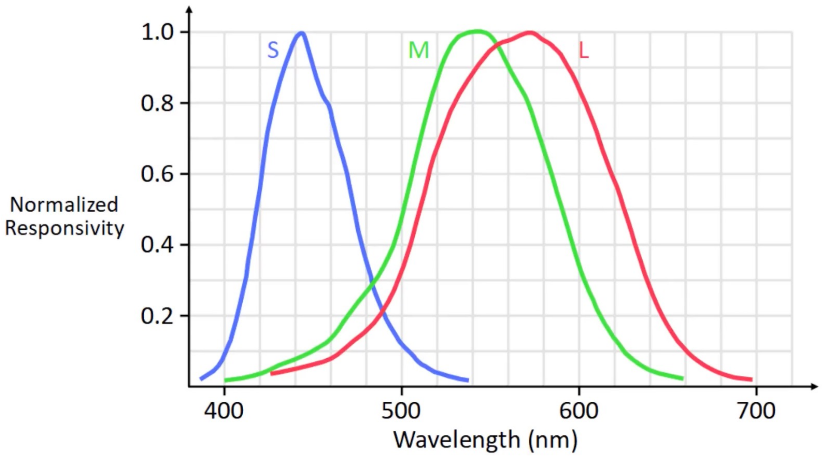
Plane of Constant luminance

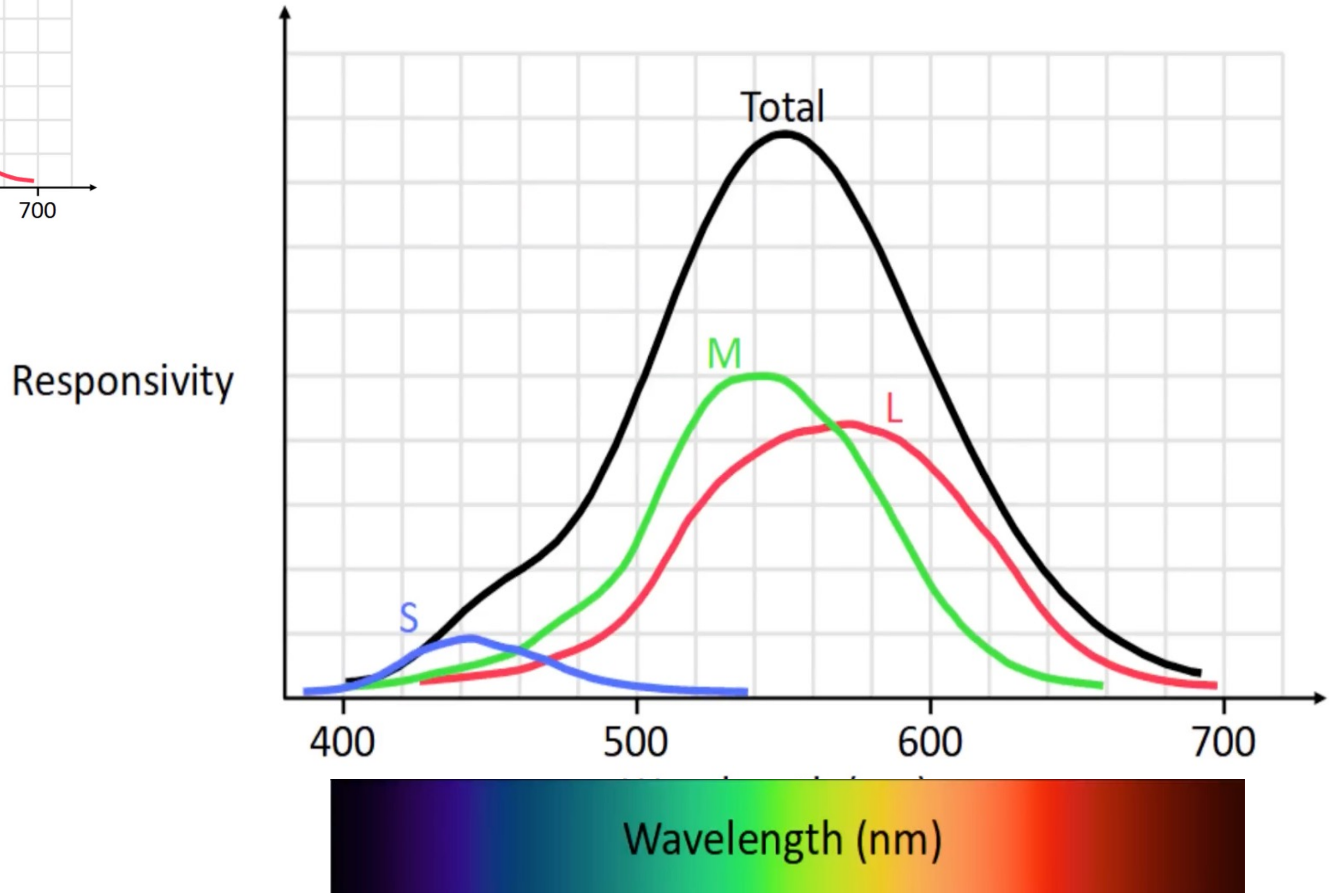




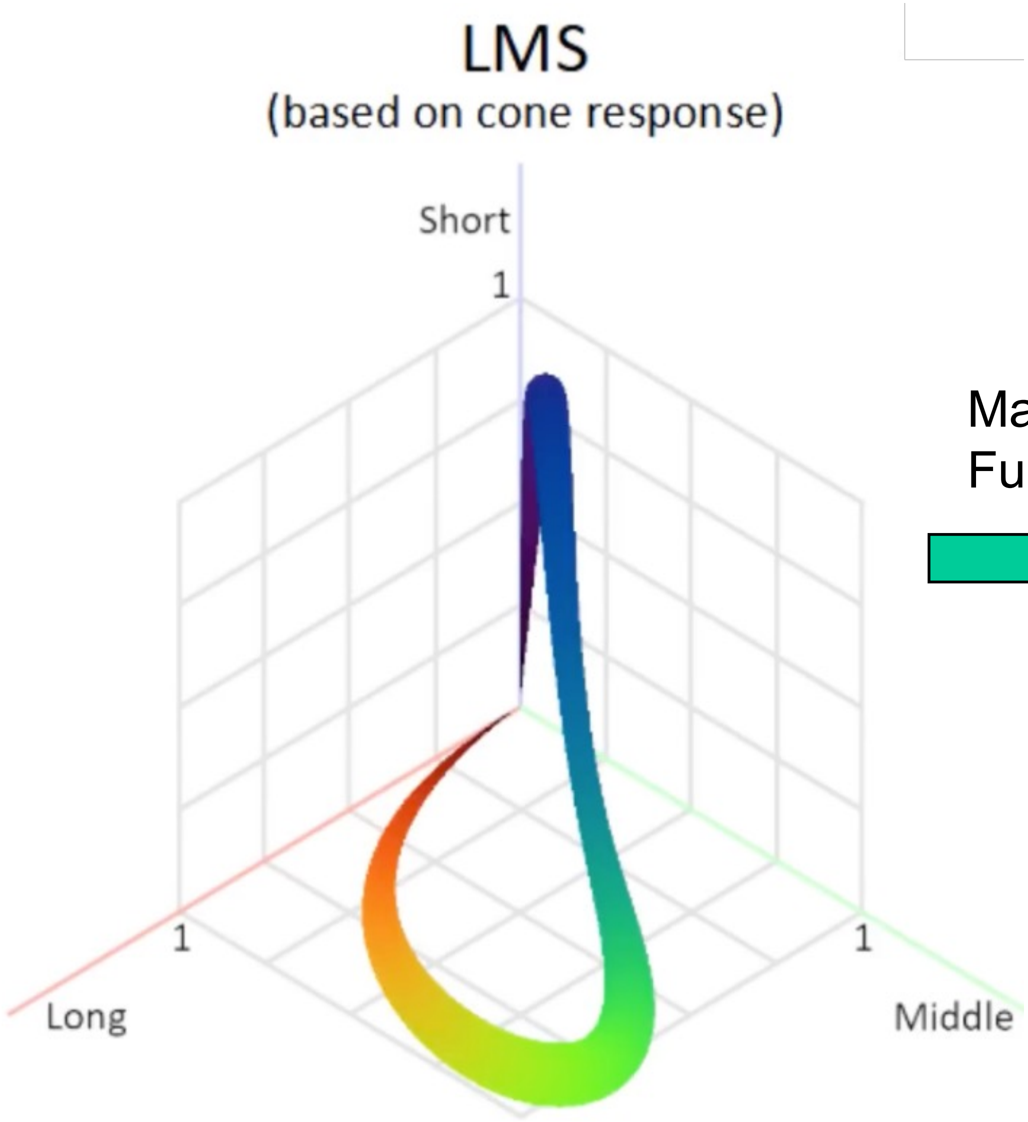


A Complication - Actual Cone Responsivity

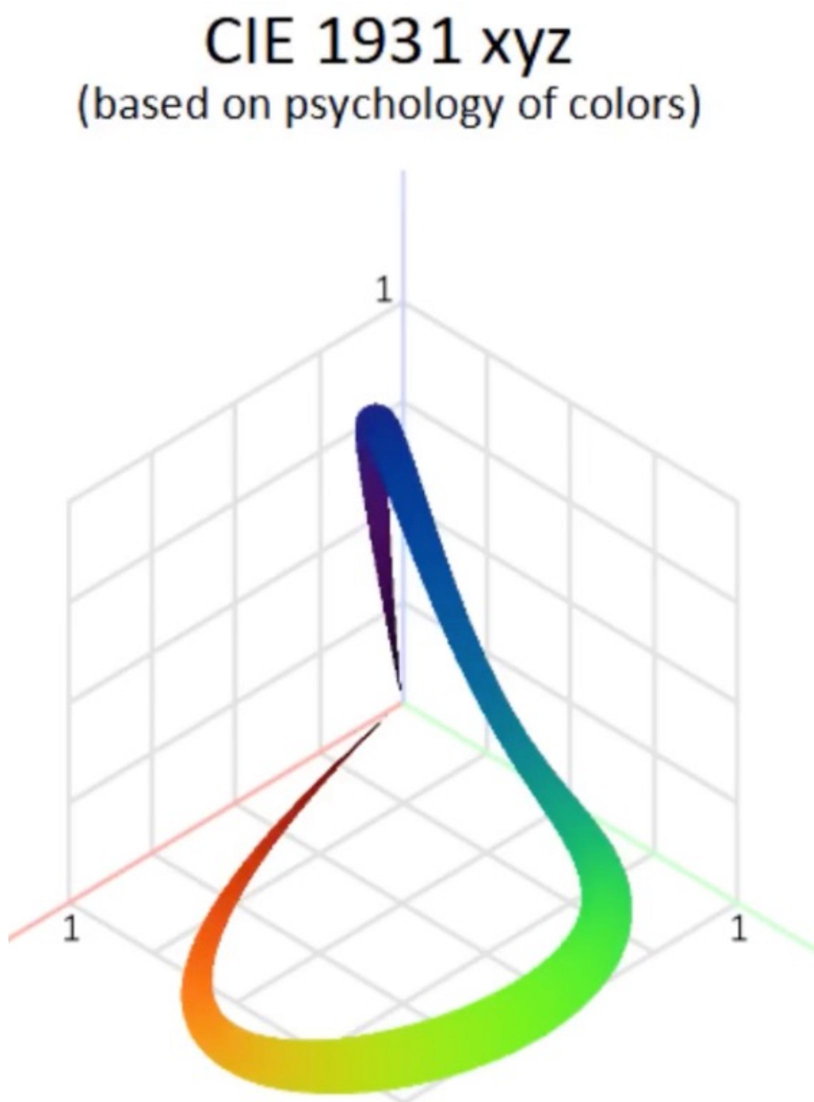




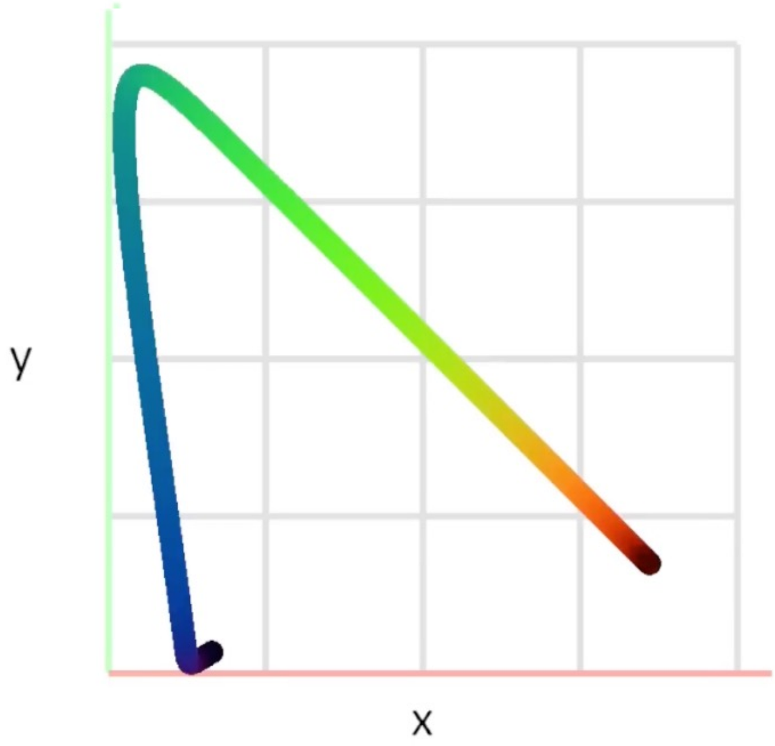
LMS vs CIE 1930 xyz Colour Spaces

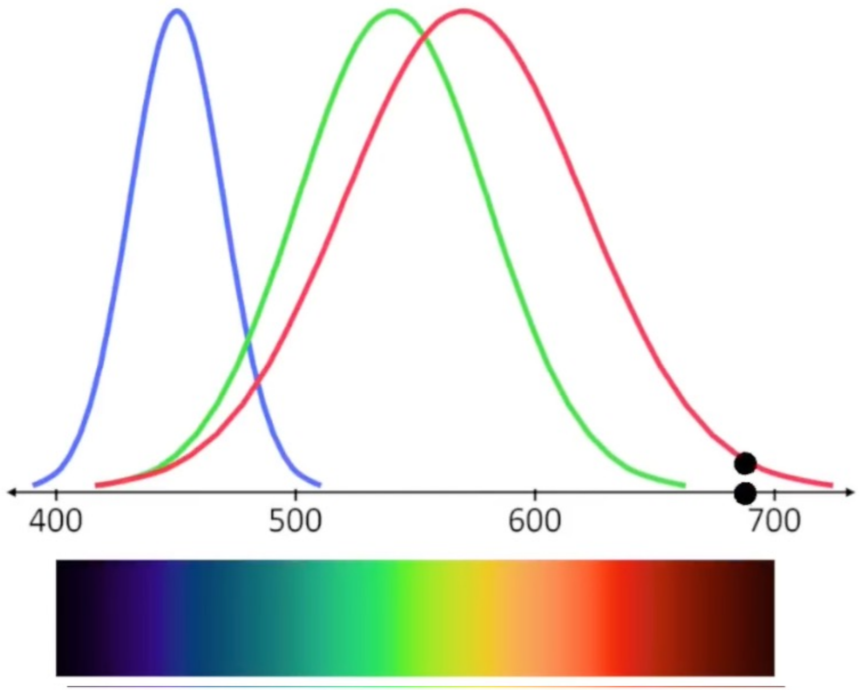


Mapping Function

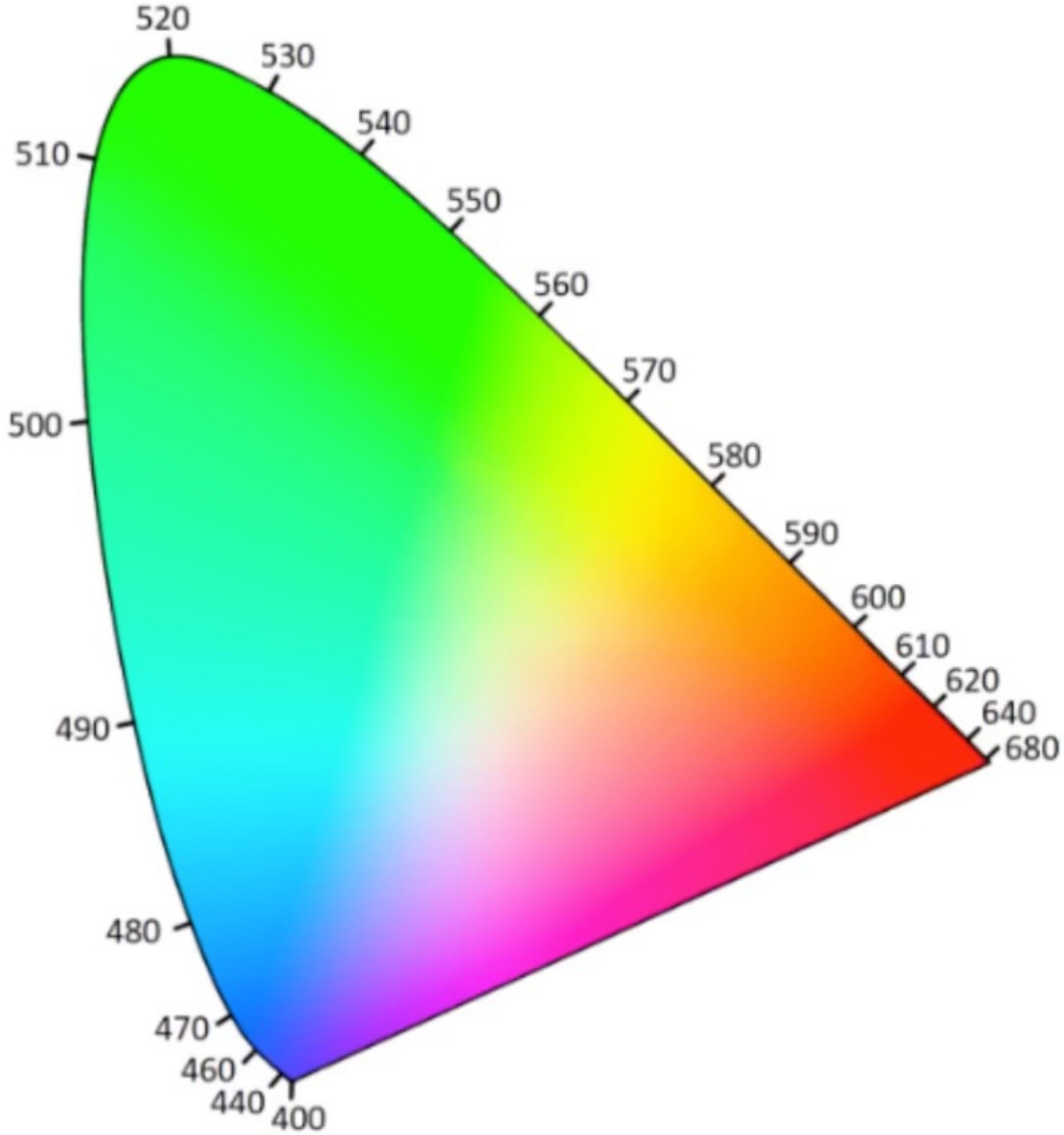


CIE 1931 xy Chromaticity Diagram - monochromatic

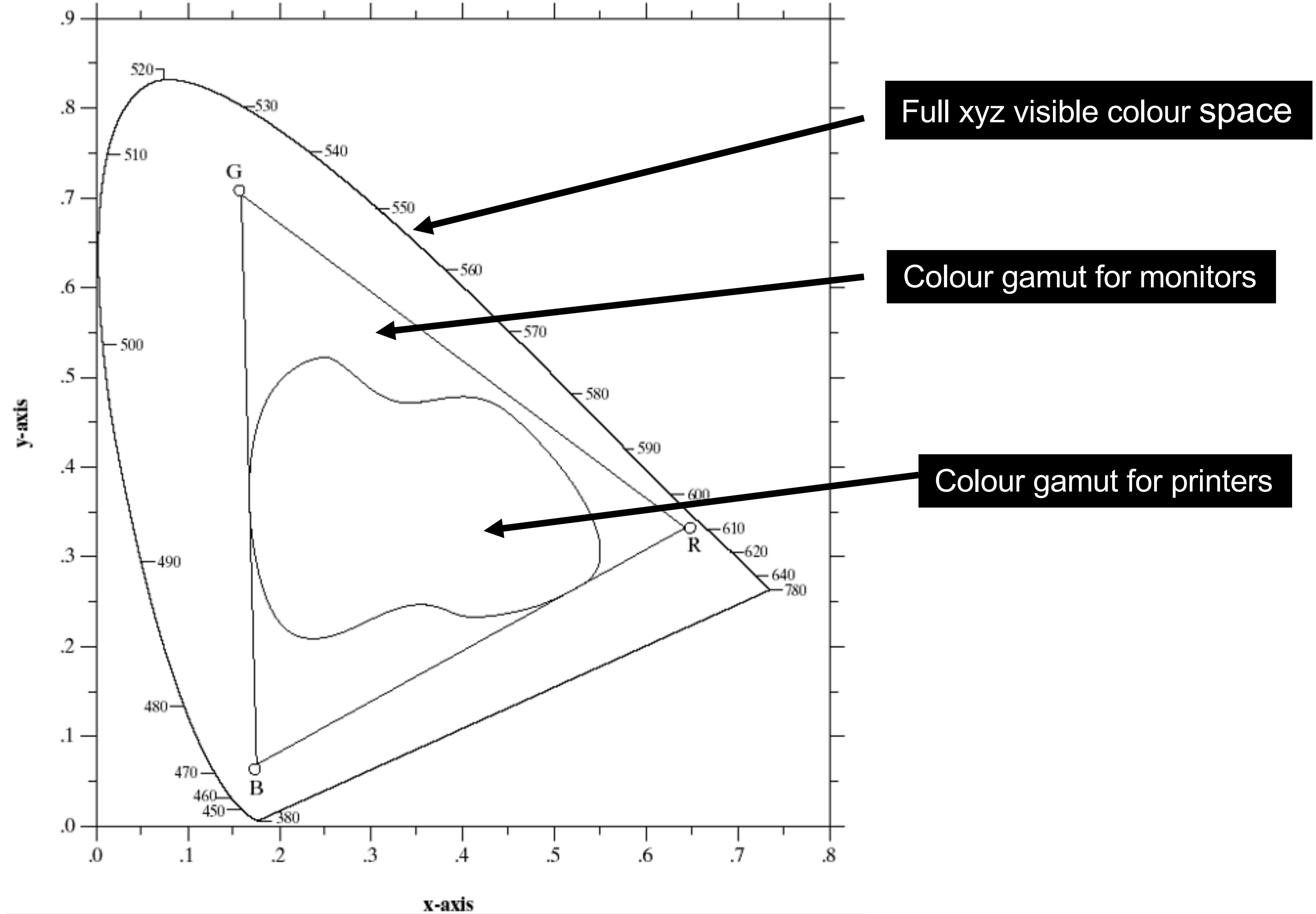




CIE 1931 xy Chromaticity Diagram

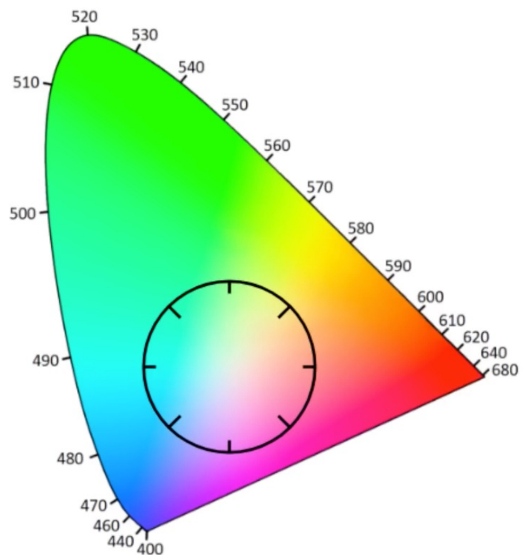


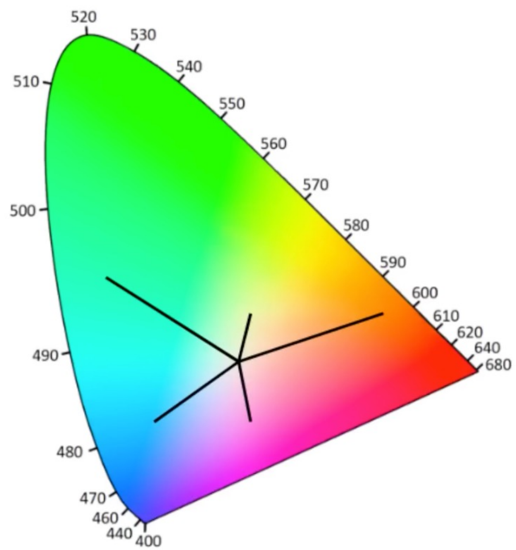
Restricted colours in printers and monitors



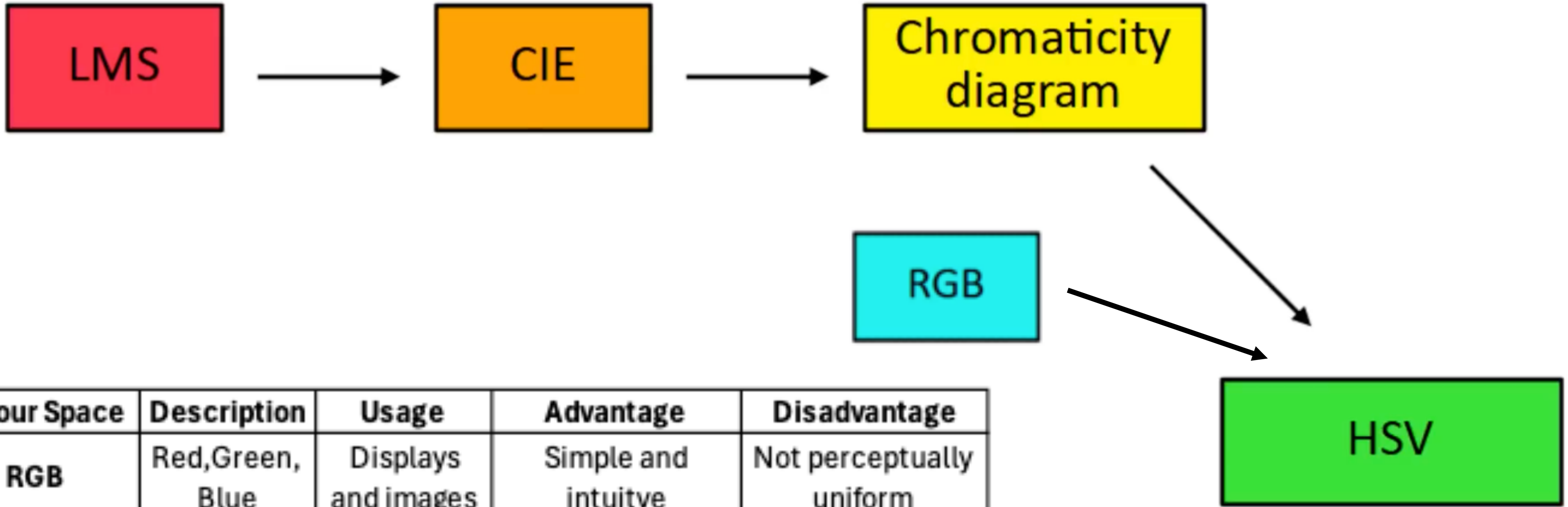
HSV Colour Space

Hue	Saturation	Value
0 to 360	0 to 100	0 to 100
~ chromaticity angle	~ chromaticity distance from center	~ luminance





Summary of Colour Spaces



Colour Space	Description	Usage	Advantage	Disadvantage
RGB	Red, Green, Blue	Displays and images	Simple and intuitve	Not perceptually uniform
LMS	Long, Medium, Short	Model human vision	Useful for testing human vision	Complex
xyz	CIE xyz	Colour standard	Device-independent	Not intuitive
HSV	Hue, Saturation, Value	User-friendly colour selection	Useful for colour pickers and image editing	Not device independent